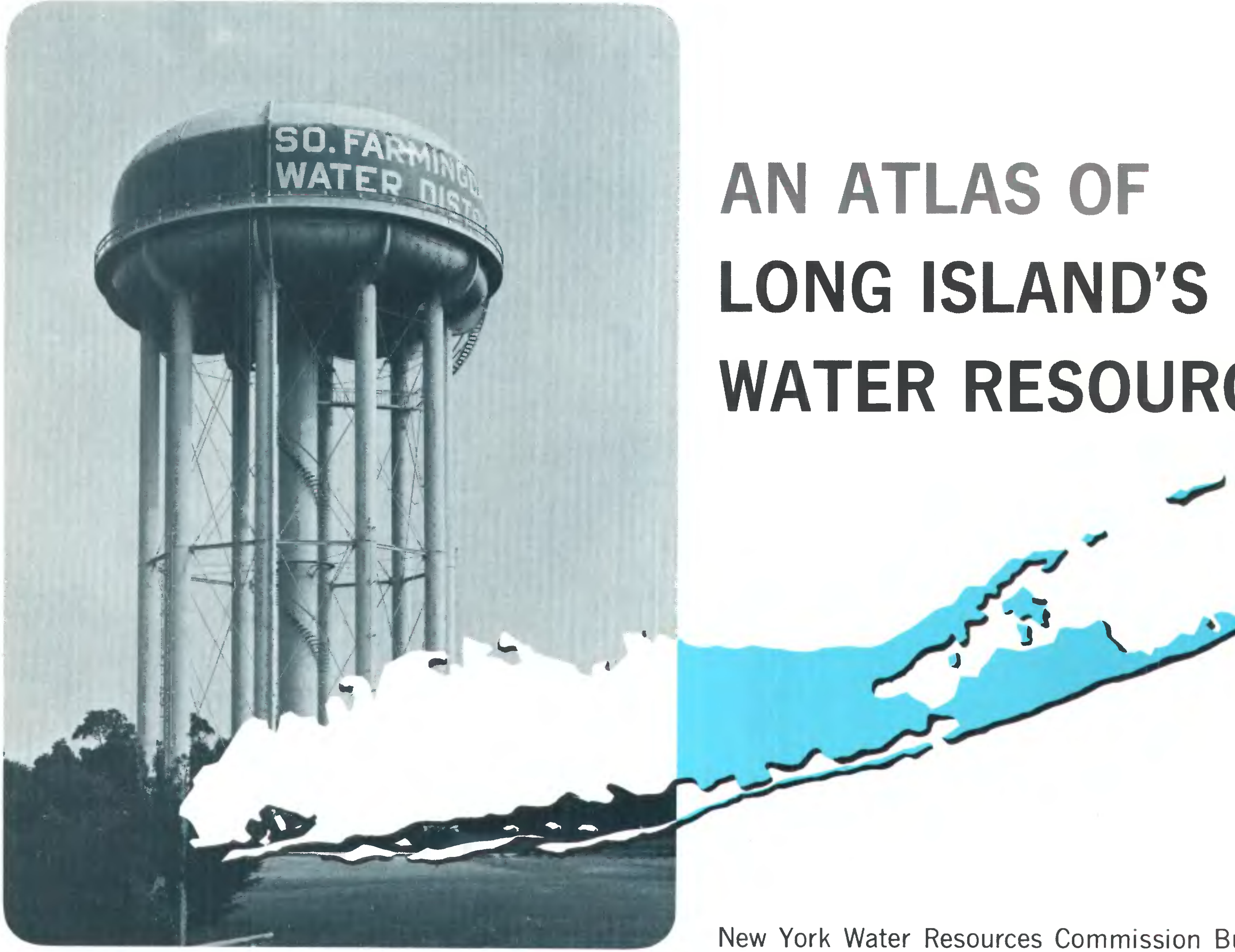

AN ATLAS OF LONG ISLAND'S WATER RESOURCES

New York Water Resources Commission Bulletin 62

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AN ATLAS OF
LONG ISLAND'S WATER RESOURCES

By

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Prepared by the U.S. Geological Survey in cooperation with the
New York State Water Resources Commission

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1968

"Long Island is the most rapidly developing area in the State, and the area where water problems are most pressing. Developing and protecting Long Island's precious underground water resources is essential for continued industrial and metropolitan development.

This Atlas is the result of many years of painstaking effort by skilled water resources specialists. For the first time it brings together a broad description of the waters of Long Island in great detail and discusses their potential for the future.

Wise water management is a product of maximum useful information plus skillful decision-making by all those concerned. The outline of water management alternatives in these pages supplies the first part of this vital equation."

Nelson A. Rockefeller

Nelson A. Rockefeller, Governor

PREFACE

The United States Geological Survey, a bureau of the U.S. Department of the Interior, has been involved in a continuous series of water-resources investigations on Long Island, N. Y., for more than thirty years. Virtually all the studies have been made in cooperation with state and county agencies. Presently, the principal cooperating agencies are the New York State Water Resources Commission, the Nassau County Department of Public Works, the Suffolk County Board of Supervisors, and the Suffolk County Water Authority.

A large amount of hydrologic data has been obtained and many technical reports have been prepared as a result of the investigations. Most of the reports have been published in the Ground Water Bulletin series of the New York State Water Resources Commission (formerly the Water Power and Control Commission), and in the water-supply paper, professional paper, and circular series of the U.S. Geological Survey. In addition, several reports have been published in scientific journals. Most of the reports are moderately to highly technical and were prepared mainly for the scientist, engineer, and professional water manager.

In 1966, the Water Resources Division of the Geological Survey undertook the preparation of the present report in cooperation with the New York State Department of Conservation, Division of Water Resources. The principal objectives of this report are to summarize and interpret some of the major results of the 30-year program of investigation of the water resources of Long Island in a manner that will be useful to the citizens of Long Island as well as to the scientist and professional water manager. Specifically, the report considers in a brief and graphical format, (a) the source, occurrence, and movement of water on Long Island—that is, the "natural hydrologic system," (b) the effects of man's activities on the system, (c) the "yield" of the system, and (d) alternative methods of developing and managing the system.

This report presents quantitative estimates of various components of the hydrologic system of Long Island—estimates that are developed mainly on the basis of previous studies on Long Island. For some of the components, however, quantitative estimates have not been made previously, and only meager data are available from which to develop them. Because these estimates are needed to round out the hydrologic picture for Long Island, they are developed for this report even though they are suitable only to illustrate the general magnitude of certain components and the need for additional work to evaluate these components.

Many of the quantitative values that are presently unavailable are being developed in an intensive water-budget study by the Geological Survey that is now in progress. Reports resulting from that study will provide more detailed and definitive information regarding many of the items considered in the present report.

This report was prepared under the immediate supervision of Mr. R. C. Heath, former district chief in charge of the U.S. Geological Survey's water-resources program in New York, and his successor, Mr. G. G. Parker. The cooperation and assistance of the numerous local, state, and Federal agencies and the innumerable private citizens who have provided help and encouragement to our colleagues during the past 30 years is gratefully acknowledged. Without their help and without the high-quality scientific work of our predecessors and contemporaries, this report would not have been possible. Special acknowledgment is due Mrs. Claudia Feingold for her diligent and effective assistance in compilation of the data and preparation of the illustrations, and Messrs. N. Drahos and J. D. Hirsch for supplying photographs used in this report.

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ILLUSTRATIONS (continued)

1 LONG ISLAND, THE LAND AND ITS PEOPLE

Location and general geographic features

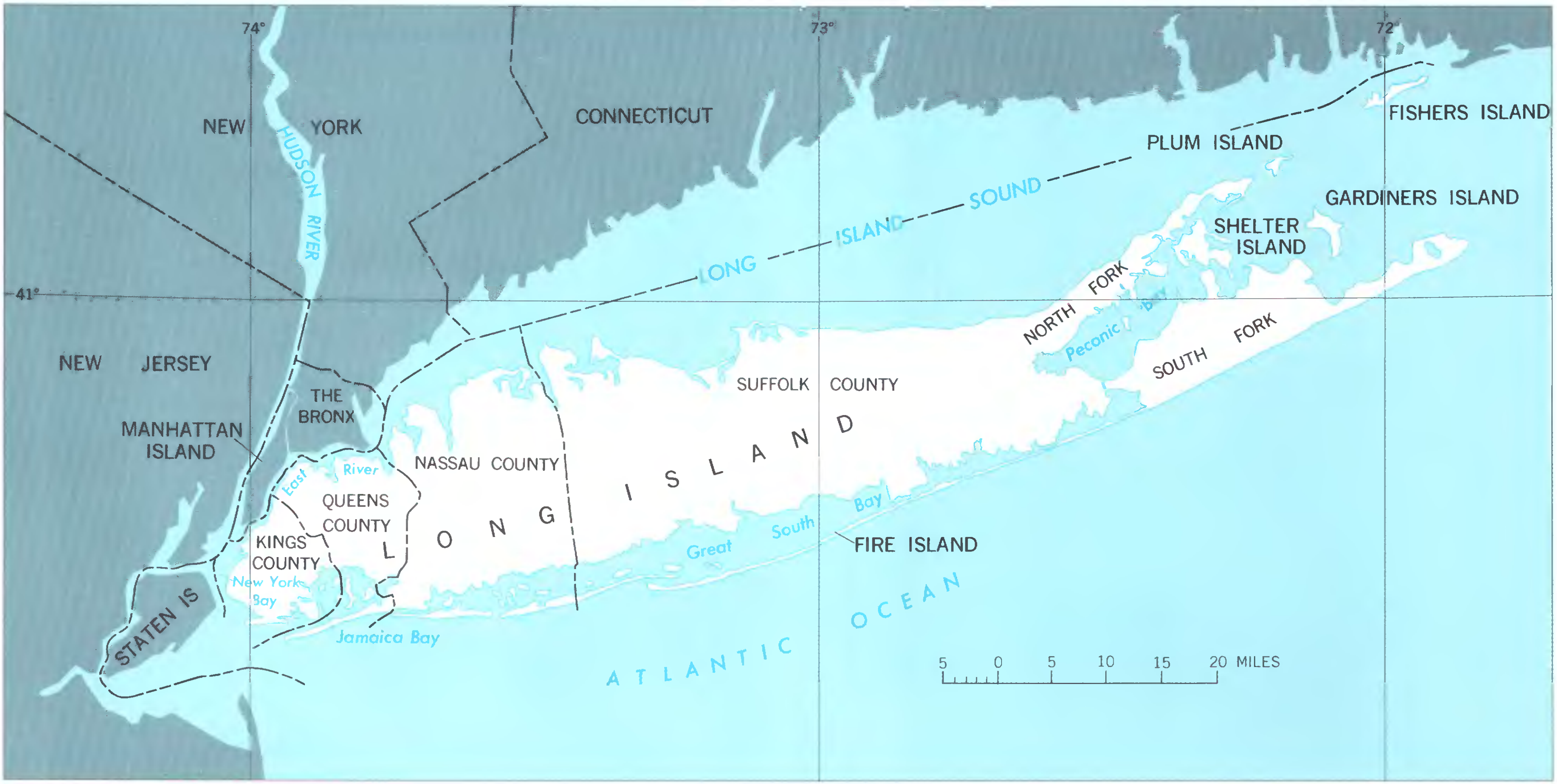
Long Island, the eastern-most part of New York State, extends east-northeastward roughly parallel to the coastline. It is bounded on the north by Long Island Sound, on the east and south by the Atlantic Ocean, and on the west by New York Bay and the East River (pl. 1A). Long Island is joined to the mainland (specifically, to the Borough of the Bronx, which is one of the five boroughs of New York City) by two bridges; it is also joined to Manhattan Island and Staten Island by several bridges and tunnels.

Politically, Long Island is divided into four counties—Kings, Queens, Nassau, and Suffolk Counties. Kings and Queens, the two westernmost counties, are also boroughs of New York City. Several smaller islands are included within the political boundaries of Long Island; the better known of these are Fire, Shelter, Gardiners, Plum, and Fishers Islands. The total length of Long Island is about 120 miles, and its maximum width is about 23 miles. The total area of Long Island (including the smaller islands within the political boundaries of the island, but excluding the bordering bays) is about 1,400 square miles. Kings County has an area of about 78 square miles; Queens County about 115 square miles; Nassau County about 291 square miles; and Suffolk County about 922 square miles.

Fire Island is the longest of several barrier beaches that parallel the south shore of Long Island. It ranges from about a quarter of a mile in width, and is separated from the main island by Great South Bay, a shallow body of salty water that ranges up to 5 miles in width. The other barrier beaches along the south shore also are separated from the main island by salty bays, one of the best known of which is Jamaica Bay along the south shore of Kings and Queens Counties.

The northern and eastern coast lines of Long Island are indented by deep bays that form excellent harbors. Peconic Bay, which is about 30 miles long, divides the eastern end of the island into two long, narrow peninsulas that are locally referred to as the North and South Forks.

PLATE 1A
LOCATION AND GENERAL GEOGRAPHIC FEATURES OF LONG ISLAND, NEW YORK



Major landforms of Long Island

The present landforms of Long Island (pl. 1B) are the result of many geologic processes, some of which began many millions of years ago and some of which began only recently. Most of the major features of the present-day topography, however, are related to the last ice age, which ended several thousand years ago. The most prominent landforms of Long Island are (a) the hills that form the "backbone" and the "forks" of the island, (b) the gently sloping plain that extends southward from the hills, (c) the deeply eroded headlands along the north shore, and (d) the barrier beaches along the south shore.

Two lines of hills, which are "terminal moraines" and reach a maximum altitude of about 400 feet, are separate and distinct in the central and eastern parts of the island, but merge in the western part. The southernmost lines of hills—the Ronkonkoma moraine—is the older of the two; it extends eastward to form the so-called South Fork. The northern line of hills—the Harbor Hill moraine—extends eastward to form the North Fork. The moraines are composed of poorly sorted rock debris consisting of boulders, gravel, sand, silt, and clay, which was pushed ahead of and incorporated within the continental ice sheets when the ice advanced onto the island, and which was deposited during melting of the ice sheets.

The moderately flat surface that extends southward from the Ronkonkoma moraine to the south-shore bays is called a glacial-outwash plain. It is mainly a depositional feature composed of and underlain by sand and gravel deposited by streams that were fed by glacial melt water. The outwash plain generally heads at an altitude of about 100–150 feet, and slopes southward at about 20 feet per mile until it merges with recent swampy deposits along the coast.

The eroded headlands along the north shore are composed mainly of glacial deposits, but streams and waves sculptured their final form. After the ice sheets melted, the land surface of Long Island rose slightly with respect to sea level. The headlands were deeply eroded, and the many wide and deep harbors along the north shore were carved by northward-flowing streams. Wave erosion has steepened the northern slopes of the headlands into nearly vertical bluffs that, in places, are about 100 feet high.

Along the south shore, waves and ocean currents reworked the deposits along the newly uplifted shore line to form off-shore bars (commonly referred to as barrier beaches). In terms of geologic time, these bars are ephemeral features that are gradually being eroded by wave action, and whose positions are continually changing owing to ocean currents. Sand and silt deposited by the wind, streams and salt-water currents, as well as organic deposits, tend to fill the shallow bays behind the barrier beaches.

PLATE 1B
MAJOR LANDFORMS OF LONG ISLAND, NEW YORK

Population growth and population density

About 6.8 million people lived on Long Island in 1965. Of these, about 2.6 million were in Kings County, 1.9 million in Queens County, 1.4 million in Nassau County, and 0.9 million in Suffolk County.

During the first two decades of the century, population growth on Long Island, in terms of both rate and magnitude, was greatest in Kings County (pl. 1C). At that time, Kings County was characterized mainly by multiple-family dwellings and was moderately industrialized; Queens County was largely suburban, and Nassau and Suffolk Counties were rural. In the next decade (the 1920's), the largest increase in population occurred in Queens County, mainly as a result of the extension of the rapid transit system into the county, the concurrent increase in construction of multiple-family dwellings, and the moderate growth of industry in the area.

Beginning soon after the end of the Second World War and extending into the late 1940's and the 1950's, marked suburban expansion into Nassau County caused a dramatic increase in the population of that county. The wave of suburban expansion, characterized mainly by large-scale developments of single-family homes, has been moving eastward with time. As a result, the population of central and eastern Nassau County increased rapidly in the mid 1950's. The population of western Suffolk County began to increase markedly in the late 1950's, and has been increasing more rapidly than the population of any other area on Long Island during the past few years.

The present (1965) population density on Long Island ranges from very dense in the western part to sparse in the eastern parts. The pattern of population density (fig. 5, pl. 1C) mainly reflects the gradual eastward transition from the highly urban communities characterized by high-rise apartment buildings in Kings County, to the suburban communities in Nassau and western Suffolk Counties, and finally to the rural areas in eastern Suffolk County. Along with the general pattern of progressive eastward decrease in population density there has been a trend of preferential urbanization along the north and south shores.

PLATE 1 C
POPULATION GROWTH, 1900–65, AND POPULATION DENSITY IN 1965, ON LONG ISLAND, NEW YORK

(Data from the U.S. Bureau of the Census and from local sources.)

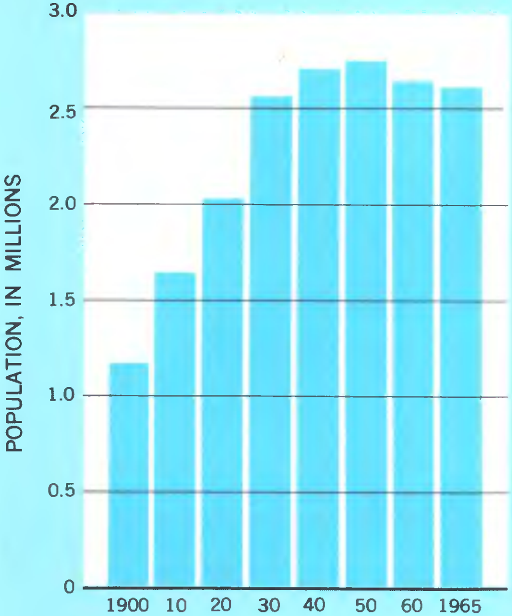


FIGURE 1. Population trends in Kings County.

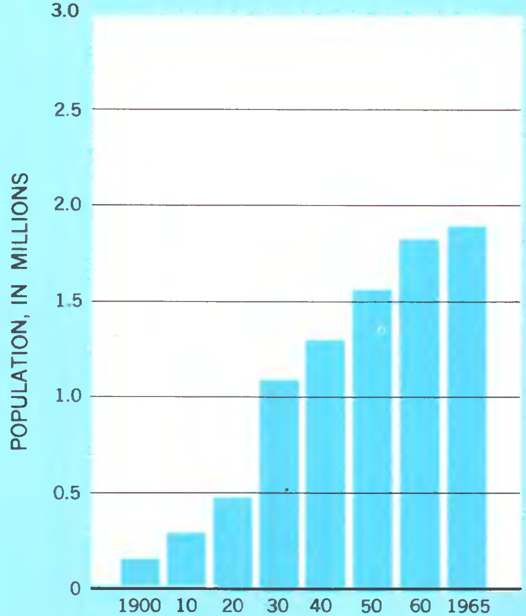


FIGURE 2. Population trends in Queens County.

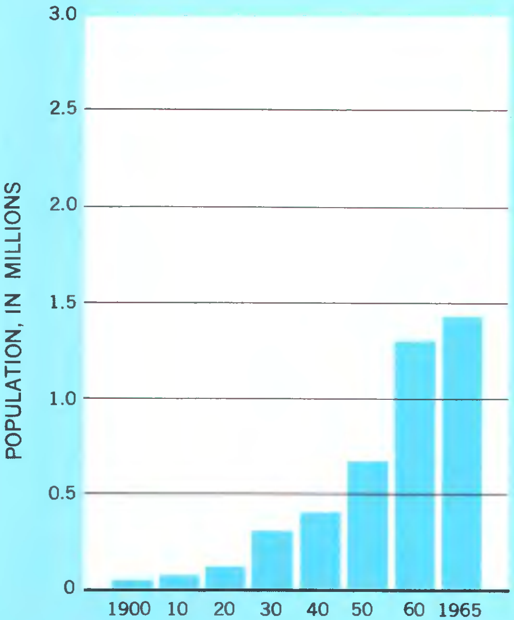


FIGURE 3. Population trends in Nassau County.

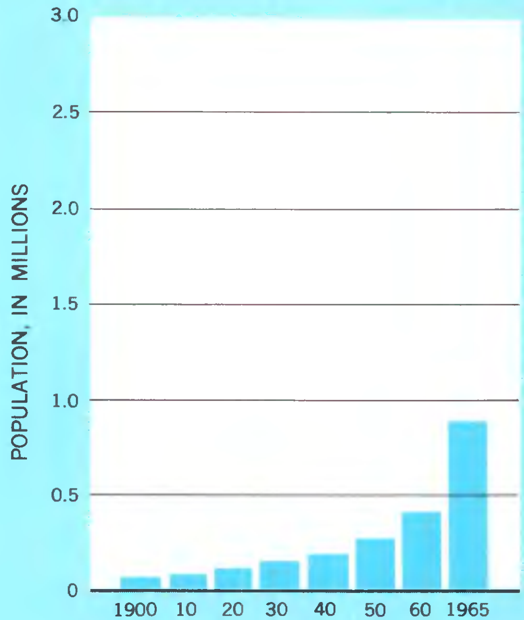


FIGURE 4. Population trends in Suffolk County.

FIGURE 5. Population density in 1965.

EXPLANATION OF MAP PATTERNS

Map symbol	Population density, in persons per square mile
(blank)	0–999
(stippled)	1,000–1,999
(light blue)	2,000–4,999
(horizontal lines)	5,000–9,999
(vertical lines)	10,000–24,999
(dark blue)	25,000–50,000

Land use in the early 1960's

The accompanying diagram (pl. 1D) showing the use of land on Long Island was compiled from reports prepared by the Nassau County Planning Commission (1959), the Suffolk County Planning Commission (1962), and the New York City Department of Planning (1962). Data for the four counties on Long Island are not available for precisely the same time. Furthermore, the three agencies did not use precisely the same land classifications nor the same methods of obtaining and evaluating the data. Despite these inconsistencies, however, the data shown on plate 1D are reasonably representative for the period designated "the early 1960's", and provide considerable insight to the general characteristics of land use on Long Island at the present time (1966).

The percentage of land occupied by streets and parkways, which is a reasonably accurate measure of the intensity of urbanization, is greatest in Kings County (about 30 percent), decreases progressively to the east, and is least in largely rural Suffolk County (less than 10 percent). Conversely, the percentage of vacant land and land that is classified as "open" increases toward the east—from less than 10 percent in Kings County to nearly 75 percent in Suffolk County. The highly suburban character of Nassau County is indicated by the fact that nearly 50 percent of the land is classified as residential, being occupied mainly by single-family homes.

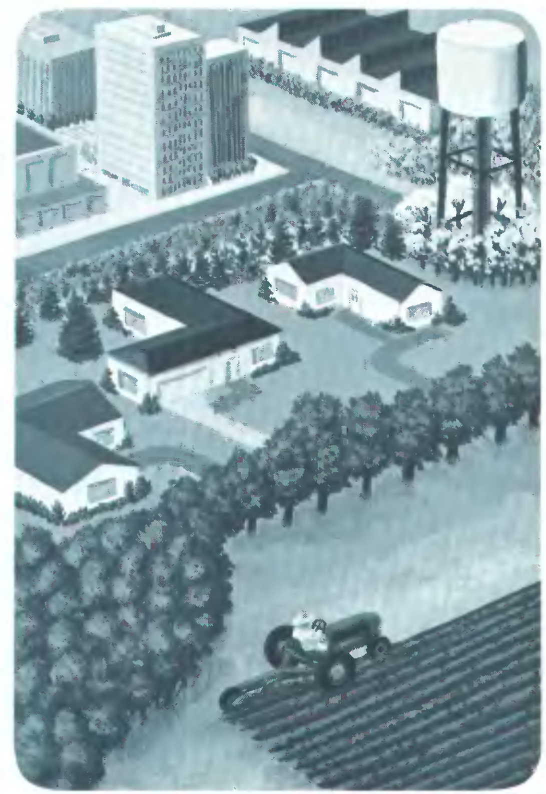
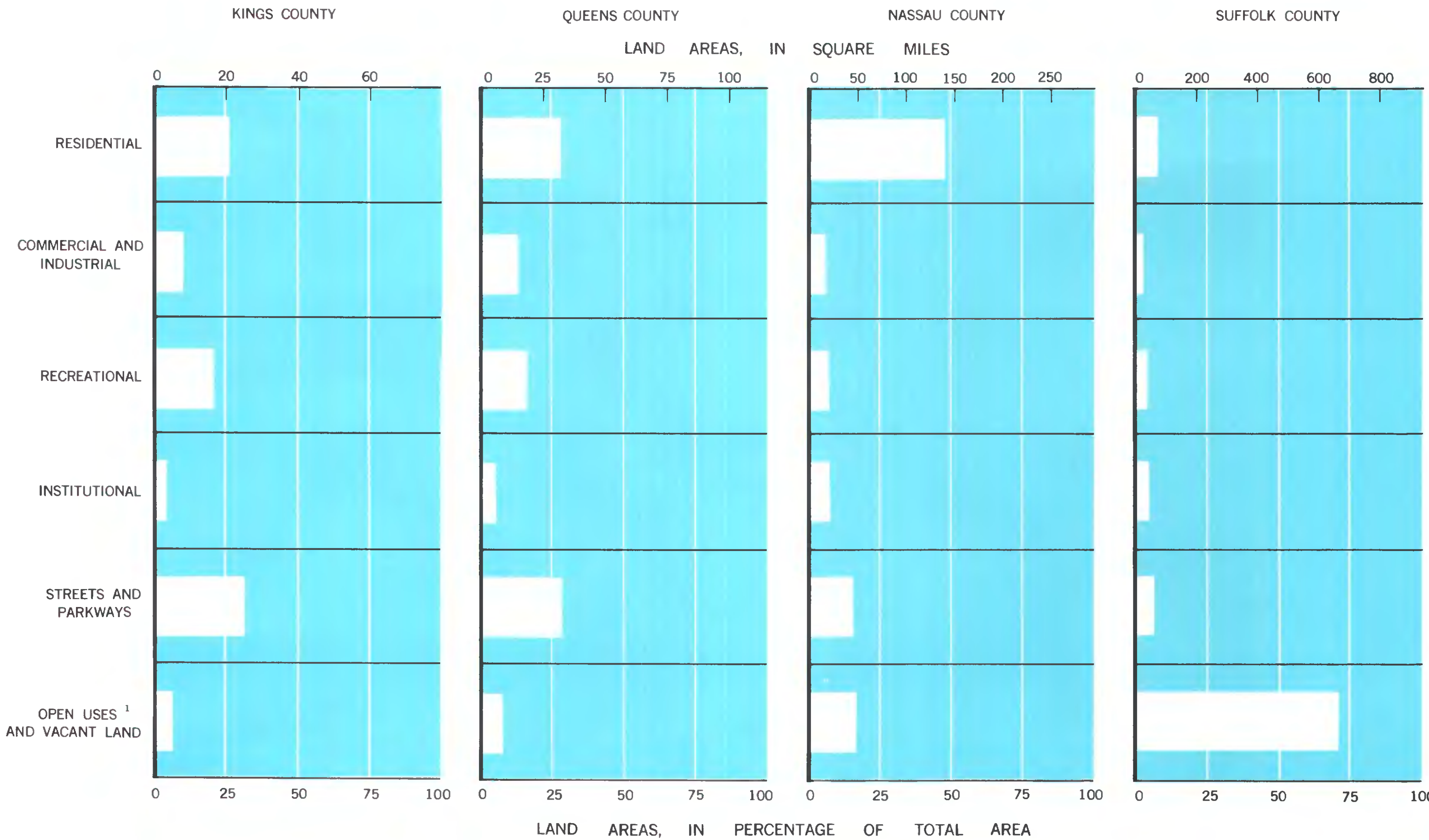


PLATE 1D
LAND USE ON
LONG ISLAND, NEW YORK,
IN THE EARLY 1960'S

(After Nassau County Planning Commission, 1959; Suffolk County Planning Commission, 1962; and New York City Department of Planning, 1962.)



[1] Open uses include farms, nurseries, junk yards, and parking lots.

2 HOW AND WHERE THE WATER IS FOUND

Classification of Long Island's water

Long Island is surrounded by an almost limitless amount of salty water—salty water in the Atlantic Ocean, in Long Island Sound, and in the many bays bordering the island. Although the salty water is important to the economy of the area and is of significant recreational value, this atlas is mainly concerned with the fresh water of Long Island, which from many standpoints, is even more important than the salty water.

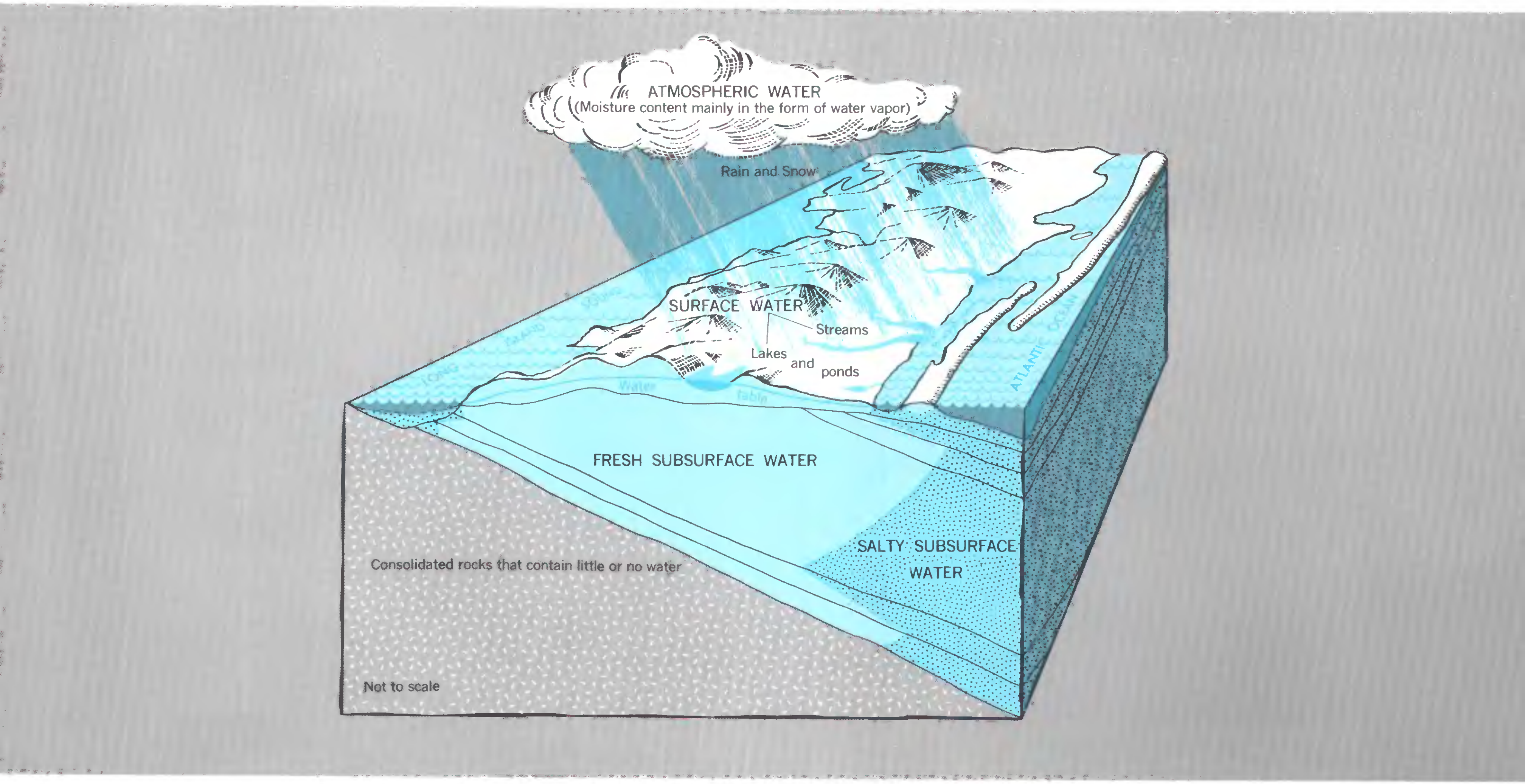
The hydrologist (water scientist) commonly classifies water into three general categories—atmospheric water, surface water, and subsurface water (pl. 2A). Atmospheric water includes water vapor (gas), droplets of rain (liquid), and particles of ice and snow (solid). Most of the time, invisible water vapor (which is derived mainly from the Atlantic Ocean by evaporation) constitutes the largest amount of water in the atmosphere above Long Island. The moisture content of the atmosphere, commonly expressed in terms of the "relative humidity", changes continually depending upon air temperature and other factors. At times maritime air masses that have a high moisture content move across Long Island from the northeast and southeast. At other times, air masses of relatively low moisture content move across Long Island from the west and northwest.

All the water on the surface of Long Island and in the bordering ocean, sound, and bays is called "surface water". The fresh-water bodies on Long Island mainly include streams, lakes, and ponds (both natural and artificial). Strictly speaking, however, ice, snow, and even puddles found on the ground soon after it rains are considered to be surface water.

The water beneath the land surface is termed "subsurface" water. Most of the subsurface water beneath Long Island is fresh; however, along the margins of the island the subsurface water becomes progressively more salty in the seaward directions until it becomes as salty as the ocean. Moreover, the subsurface water along the margins of the island generally becomes progressively more salty with depth. Locally, however, bodies of fresh ground water underlie bodies of salty ground water (pl. 2A).

Under natural conditions precipitation (mainly rain and snow) was the ultimate source of all the fresh surface and subsurface water on Long Island. The Atlantic Ocean and Long Island Sound are the sources of nearly all of Long Island's salty surface and subsurface water. At places, as in some of the bays and in the lower reaches of most of the streams, the fresh and salty surface water intermix, and the resulting mixture is termed "brackish" water.

PLATE 2A
CLASSIFICATION OF LONG ISLAND'S WATER



Fresh surface-water bodies

The larger and better known fresh surface-water bodies on Long Island are shown on plate 2B. The identification numbers are those formally assigned by the U.S. Geological Survey to the gaging stations at the streams. All the bodies of fresh surface water shown on the map are perennial—that is, they contain water during the entire year. In addition, all the streams are estuarine and have salty water in their lower reaches.

In overall aspect, the present locations of Long Island's streams were determined mainly by the ancient drainage pattern that developed during the last ice age. Accordingly, most of the streams flow in broad, shallow valleys that were formed by the much larger streams which existed during melting of the ice sheet. All the southward-flowing streams have gentle gradients that, throughout most of their reaches, average about 10 feet per mile. The northward-flowing streams generally have steeper gradients that average about 20–40 feet per mile.

Two distinctly different types of natural lakes and ponds are found on Long Island—water–table and perched lakes and ponds. (See p. 20 for explanation of the term "water table".) Lake Ronkonkoma is a water-table lake, its bottom extending to a depth of about 60 feet below the water table. Lake Success is one of the better known examples of a perched lake on Long Island. Both of these lakes and many other natural lakes and ponds on Long Island, including Lake Panamoka, are sometimes referred to as "kettle-hole" lakes. Such lakes fill depressions formed by blocks of ice that were buried during the last ice age and subsequently melted. Numerous artificial lakes and ponds have been built on Long Island. The larger ones were formed by the construction of low dams across streams. Hempstead and Belmont Lakes are well known examples of this type of lake.

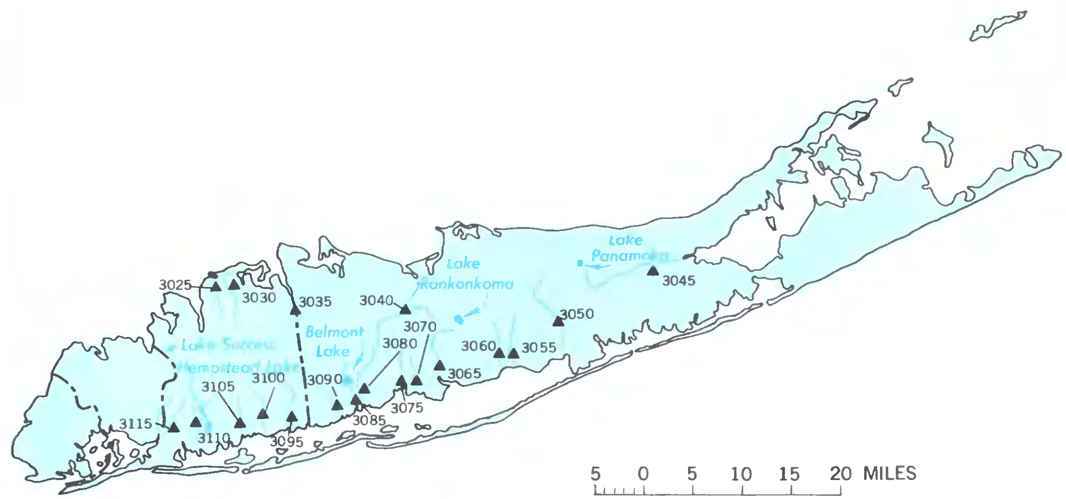
During the 19th and the early part of the 20th century, Long Island's streams, lakes, and ponds were used extensively as sources of water supply and for power to operate sawmills and gristmills. Presently, only insignificant quantities of surface water are used for water supply, and all the mills have been abandoned. The surface-water bodies of Long Island are, however, used extensively for recreation.

The names of the streams shown on plate 2B, their surface-drainage areas, and their average flows are listed in the following table. Other aspects of the hydrology of Long Island's streams are considered in subsequent chapters of this atlas.

PLATE 2B
FRESH SURFACE-WATER BODIES
ON LONG ISLAND, NEW YORK

Identification number of streamflow-measuring station	Name of stream	Surface drainage area (square miles)	Average flow (cfs[1])
1-3025	Glen Cove Creek	11	7.2
-3030	Mill Neck Creek	12	9.5
-3035	Cold Spring Brook	7	4.6
-3040	Nissequogue River	27	42.2
-3045	Peconic River	75	35.5
-3050	Carmans River	71	24.2
-3055	Swan River	9	13.0
-3060	Patchogue River	14	21.2
-3065	Connetquot River	24	39.4
-3070	Champlin Creek	7	7.5
-3075	Penataquit Creek	5	6.2
-3080	Sampawams Creek	23	9.8
-3085	Carlls River	35	27.7
-3090	Santapogue Creek	7	4.6
-3095	Massapequa Creek	38	11.9
-3100	Bellmore Creek	17	11.2
-3105	East Meadow Brook	31	17.5
-3110	Pines Brook Outlet	10	5.1
1-3115	Valley Stream	4	4.8

[1] Cubic feet per second



EXPLANATION

3035

Streamflow-measuring station, and identification number

Lake or pond

Major hydrogeologic units of the ground-water reservoir

As shown in the accompanying diagram (pl. 2C), Long Island is underlain by consolidated bedrock, which in turn is overlain by a wedge-shaped mass of unconsolidated rock materials. The top of the bedrock, which is at or near land surface in the northwest part of the island, dips toward the southeast to a depth of about 2,000 feet in south-central Suffolk County.[1] The consolidated bedrock is dense and does not store or transmit appreciable amounts of water.

The materials that overlie the bedrock and constitute Long Island's ground-water reservoir are unconsolidated deposits of gravel, sand, silt, and clay and mixtures thereof. These materials can be classified into several hydrogeologic units on the basis of hydraulic properties, relative position, composition, geologic age, and other characteristics. The more important water-producing units in the ground-water reservoir are termed aquifers. Pertinent characteristics of the major units of the ground-water reservoir are summarized in the following table:

[1] The actual dip of the upper bedrock surface is slightly less than one degree to the southeast. The much greater apparent inclination of the bedrock surface and Magothy aquifer that is shown on plate 2C is due to the very great exaggeration of the vertical scale in this cross-section.

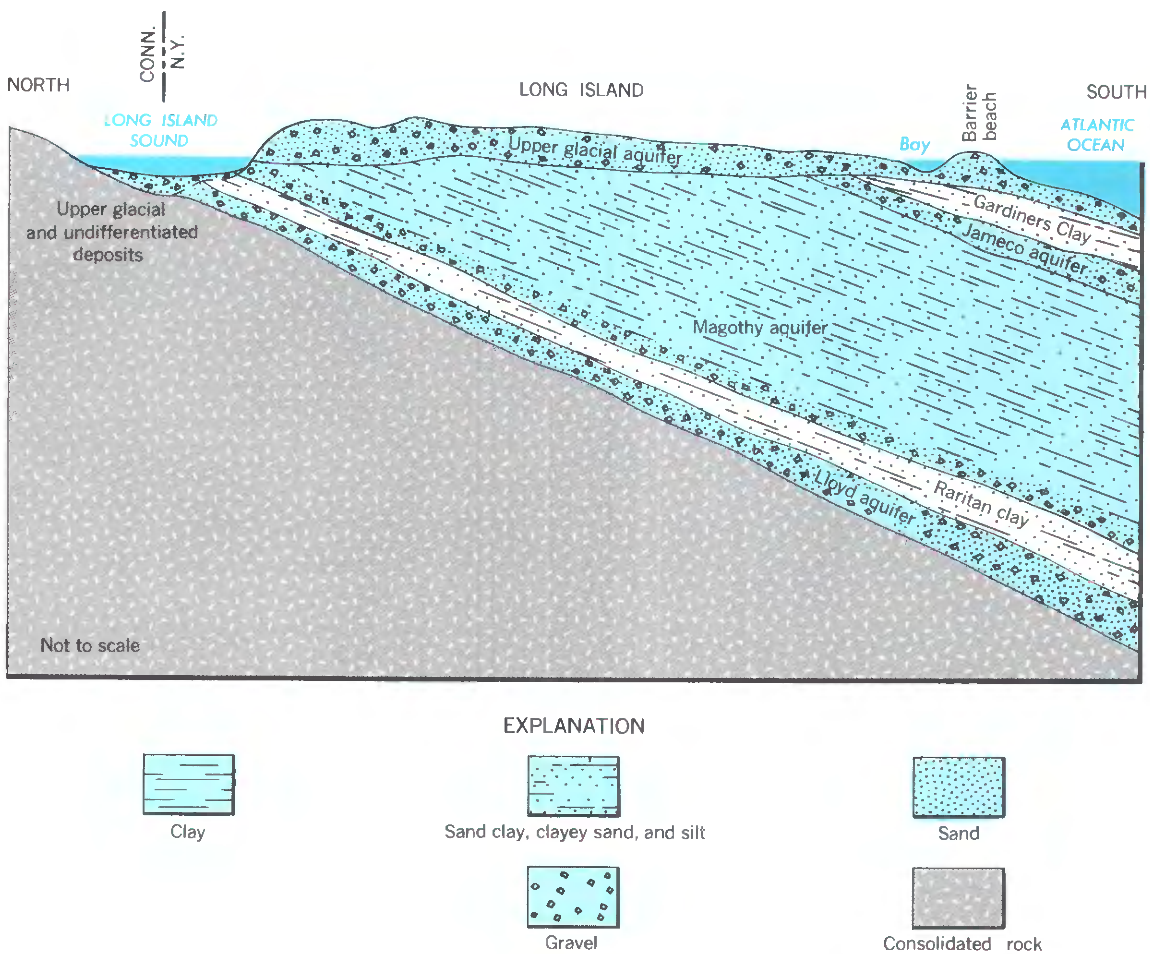
Hydrogeologic unit	Geologic name [2]	Approximate maximum thickness (feet)	Water-bearing character
Upper glacial aquifer	Upper Pleistocene deposits	400	Mainly sand and gravel of moderate to high permeability; also includes clayey deposits of glacial till of low permeability.[3]
Gardiners Clay	Gardiners Clay	150	Clay, silty clay, and a little fine sand of low to very low permeability.
Jameco aquifer	Jameco Gravel	200	Mainly medium to coarse sand of moderate to high permeability.
Magothy aquifer	Magothy(?) Formation	1000	Coarse to fine sand of moderate permeability; locally contains gravel of high permeability, and abundant silt and clay of low to very low permeability.
Raritan clay	Clay member of the Raritan Formation	300	Clay of very low permeability; some silt and fine sand of low permeability.
Lloyd aquifer	Lloyd Sand Member of the Raritan Formation	300	Sand and gravel of moderate permeability; some clayey material of low permeability.

[2] Names are those used in reports by the Geological Survey. Perlmutter and Todd (1965, p. 9) proposed that the Magothy(?) Formation be divided into the Monmouth Group and the Matawan Group and Magothy Formation undifferentiated.

[3] Permeability denotes how readily water can move through porous material.

PLATE 2C

MAJOR HYDROGEOLOGIC UNITS OF THE GROUND-WATER RESERVOIR OF LONG ISLAND, NEW YORK



Subsurface water

Below a certain level underground (called the "water table") the open spaces or pore spaces between the particles of clay, silt, sand, and gravel are completely filled with water under atmospheric or greater pressure (pl. 2D). This part of the earth is the "zone of saturation", and the water contained therein is called ground water. In this atlas, the terms "zone of saturation" and "ground-water reservoir" are used interchangeably.

The pore spaces of the material between the water table and the land surface are filled with a mixture of air, liquid water, and water vapor and other gases. This part of the earth is called the zone of aeration, and the water contained therein is called vadose water. Hydrologists commonly refer to the vadose water in the soil zone just below the land surface as soil water; water in the layer immediately above the water table commonly is called capillary water. One of the major differences between ground water and vadose water is that ground water will flow into a well under the force of gravity and vadose water will not.

The aquifers on Long Island contain ground water under two distinctly different conditions—water table and artesian. Ground water under water-table conditions sometimes is referred to as unconfined ground water, and the aquifers in which it occurs commonly are called unconfined aquifers. Similarly, artesian ground water and the aquifers in which it occurs commonly are referred to as confined ground water and confined aquifers, respectively.

Ground water in the uppermost part of the zone of saturation (mainly in the upper glacial aquifer, but locally also in the Magothy aquifer) is under water-table conditions. Throughout most of Long Island, the hydraulic head in the unconfined aquifers (shown by the altitude of the water level in wells tapping only those aquifers) is at or near the altitude at which the ground water is first found.

Artesian conditions predominate in most of the other parts of the ground-water reservoir of Long Island, where the saturated deposits are overlain and confined by silty and clayey layers of low permeability. The hydraulic head in the confined aquifers ranges from several feet below the water table to nearly 20 feet above it. At places along the north and south shores and the barrier beaches, the artesian pressure in the Lloyd aquifer is high enough so that the hydraulic head is above land surface, causing some wells that penetrate that aquifer to flow.

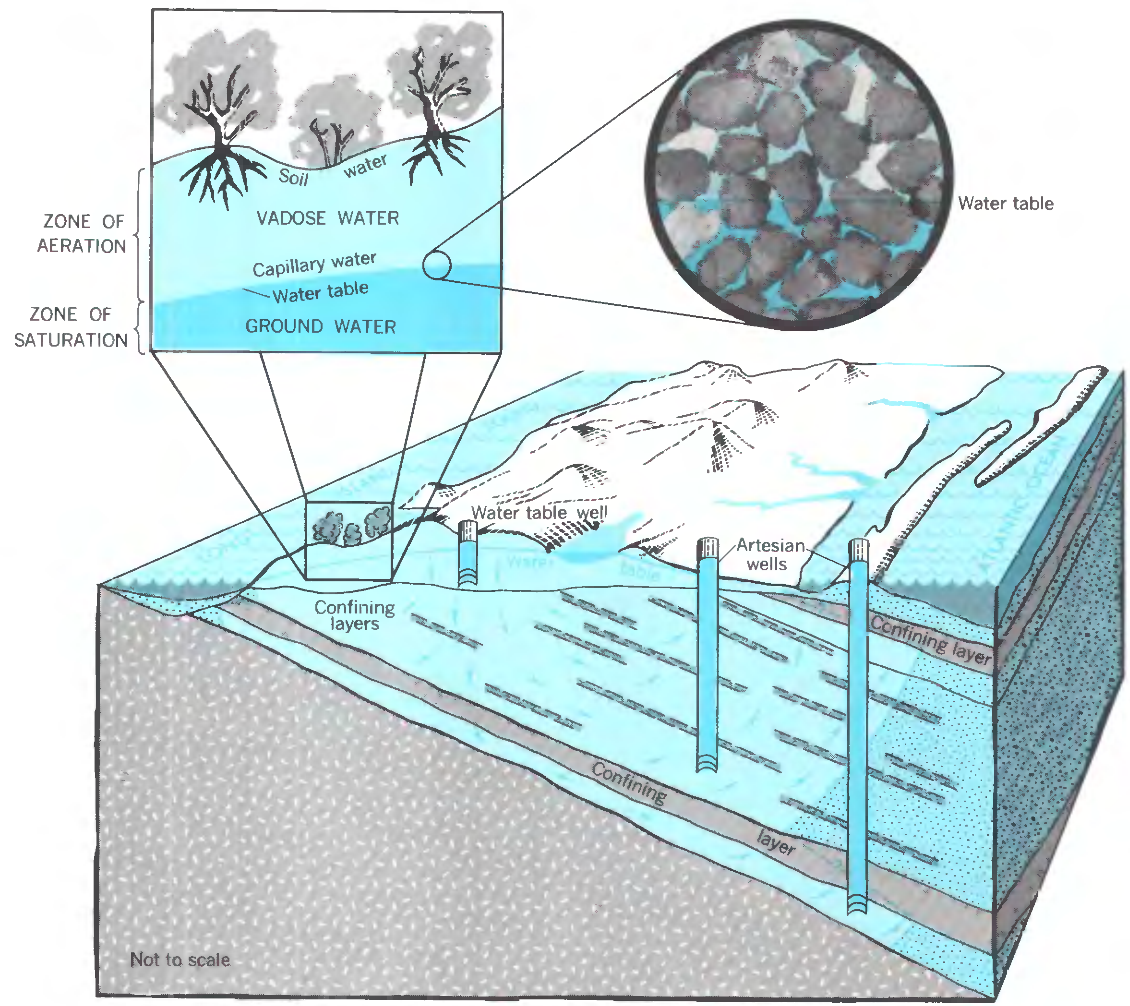
In addition to the Raritan clay, the other major well-defined confining layer in the ground-water reservoir of Long Island is the Gardiners Clay. This unit locally confines water in the Jameco aquifer and in the Magothy aquifer in the areas in which it occurs near the north and south shores. Numerous clayey and silty layers in the Magothy aquifer and clay beds in the upper glacial aquifer also are important confining layers. Throughout most of Long Island, where the Gardiners Clay is missing, the clayey and silty layers within the Magothy aquifer function as confining layers. Normally, the degree of confinement in the Magothy aquifer increases with depth as more and more clayey layers intervene between the deep zone and the water table.

Although the confining layers are of sufficiently low permeability to restrict the flow of water through them, they are not completely impermeable. Therefore, there is at least slight hydraulic continuity between the more permeable layers that are separated by confining layers. In other words, at many places on Long Island, ground water flows slowly

PLATE 2D
SUBSURFACE WATER ON
LONG ISLAND, NEW YORK

through confining layers from one more permeable layer to another. Moreover, locally some of the confining layers have been breached by ancient erosional channels, which were later backfilled with material of moderate to high permeability. In such areas, moderately large amounts of water may flow vertically.

Water-table aquifers and artesian aquifers differ markedly in their response to pumping. Water pumped from a water-table aquifer is derived mainly by gravity drainage of the aquifer materials near the pumping well as the water table is lowered. In an artesian aquifer, on the other hand, as the hydraulic head is lowered because of pumping, water is released from storage mainly by compression of the aquifer and expansion of the water. As a result, the amount of water released from a water-table aquifer per unit decline in head per unit area commonly is hundreds of times greater than the amount released from an artesian aquifer. Accordingly, hydraulic-head effects, such as the lowering of water levels near a pumping well, ordinarily occur much sooner and are of a much greater magnitude in artesian aquifers than in water-table aquifers.



Contours on the water table in 1965

The water-level contours on the accompanying map (pl. 2E) show the altitude of the top of the unconfined fresh ground-water body beneath the land surface of Long Island. The surface defined by these contours roughly conforms to the land-surface topography—that is, the water table generally is at the highest altitude beneath the hills formed by the terminal moraines, and decreases in altitude as the land surface slopes away from the hills toward the sea. At the shorelines, the water table is at or near sea level.

The water table in 1965 was characterized by two prominent highs—one in Nassau County that had a maximum altitude of somewhat more than 80 feet, and the other in Suffolk County that had a maximum altitude of about 60 feet. These highs in the water table are natural features in the sense that their altitude and location have been only slightly affected by the activities of man. Other noteworthy features in 1965 were the two depressions in the water table, one in central Queens County and the other in northwestern Kings County. The upper surface of the fresh ground-water body in both those depressions was below sea level. These depressions are mainly related to the activities of man (p. 82).

Sufficient data are not available to prepare maps of all of Long Island showing the piezometric (hydraulic-head) surfaces for the artesian aquifers underlying the island. However, such maps have been prepared for Nassau and Queens Counties, and presently are being readied for publication. These maps and data available for other parts of Long Island show that the piezometric surfaces have the same general shapes as the water table. However, along the east-west axis of the island, the piezometric surfaces are at altitudes somewhat lower than the water table (usually not more than several feet); whereas, near the coast, the piezometric surfaces are at altitudes somewhat higher than the water table.

Knowledge of the shape and altitude of the water table is useful in many ways. For example, in most places the depth below land surface at which ground water will first be found can be determined by subtracting the altitude of the water table from the altitude of the land surface. In addition, inasmuch as ground water flows in a direction at right angles to the contours (from areas of higher to areas of lower water-table altitude), the horizontal component of the direction of ground-water movement can be deduced from the water-level contours.

PLATE 2E
GENERALIZED CONTOURS ON THE WATER TABLE
OF LONG ISLAND, NEW YORK, IN 1965

5 0 5 10 15 20 MILES

EXPLANATION

WATER-TABLE CONTOUR
Shows altitude of water table
Contour interval 5, 10, and 20 feet
Datum is mean sea level

Definition of the "water-budget area" and the "index period"

In the following sections of the report, quantitative values for the components of the hydrologic system of Long Island are derived or estimated for the so-called water-budget area (pl. 2F) rather than for the entire island. The water-budget area, which includes about 760 square miles, is bounded on the west by the border between Nassau and Queens Counties. The eastern boundary is an imaginary north-south line that separates the North and South Forks from the main part of Long Island; the northern boundary follows roughly, but with local departures, the northern shoreline; and the southern boundary is a curved line that joins the streamflow-measuring stations on the major streams that drain into the bays along the south shore.

Kings and Queens Counties are excluded from the water-budget area mainly because intensive urbanization and other related factors (which are considered subsequently in this report) make it difficult to obtain the data needed to develop certain quantitative values for these counties. The forks are excluded from the water-budget area because, hydrologically, these areas are largely independent of the remainder of Long Island. The areas seaward of the streamflow-measuring stations are excluded from the water-budget area mainly because of the complex iintermixing of fresh and salty surface and ground water, and the resulting difficulty in accurately measuring streamflow and evapotranspiration within the near-shore lowlands.

Whenever possible, quantitative values are developed for the index period water years[1] 1940–65. This 26–year period was chosen mainly because it is the longest continuous period for which comparable streamflow, ground-water, and climatological data are available.

[1] The water year is the 12–month period beginning on October 1 and ending on September 30; it is designated by the calendar year in which it ends.

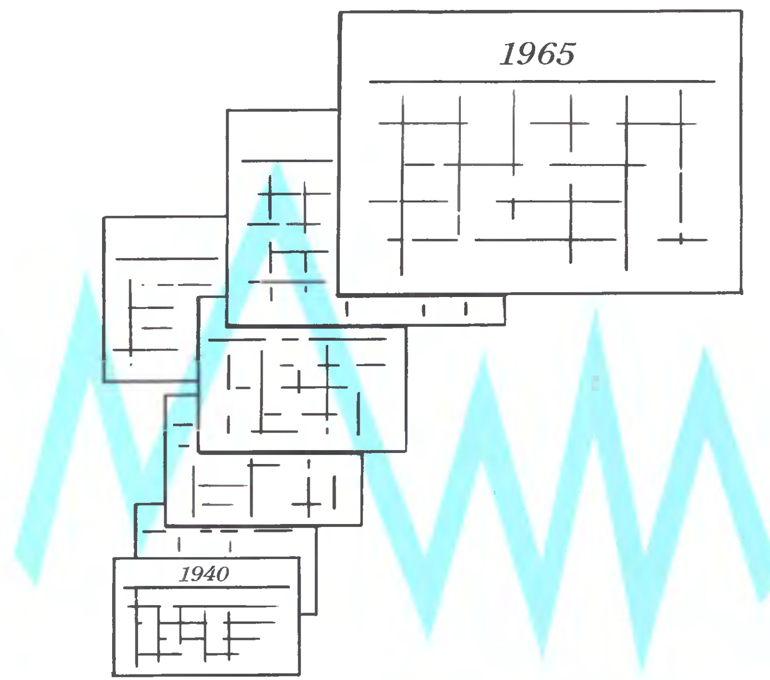


PLATE 2F

LOCATION OF THE WATER-BUDGET AREA
OF LONG ISLAND, NEW YORK

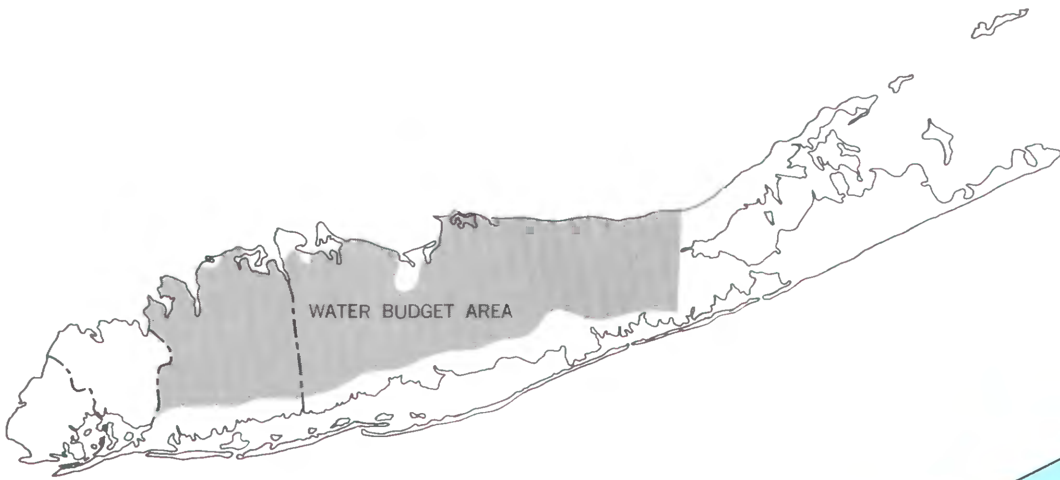


FIGURE 1. Areal extent of the water-budget area.

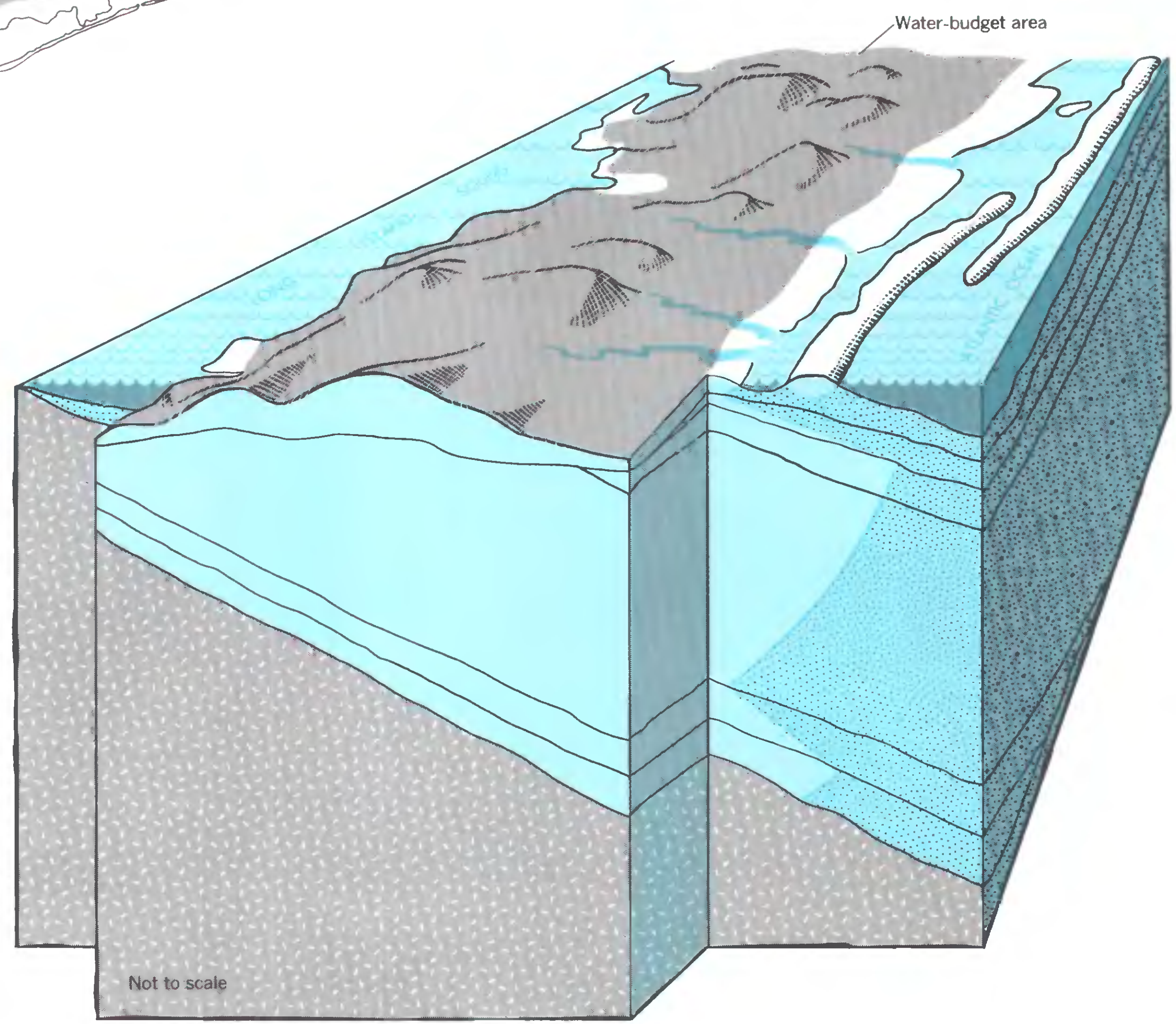


FIGURE 2. Relief and subsurface character of the water-budget area.

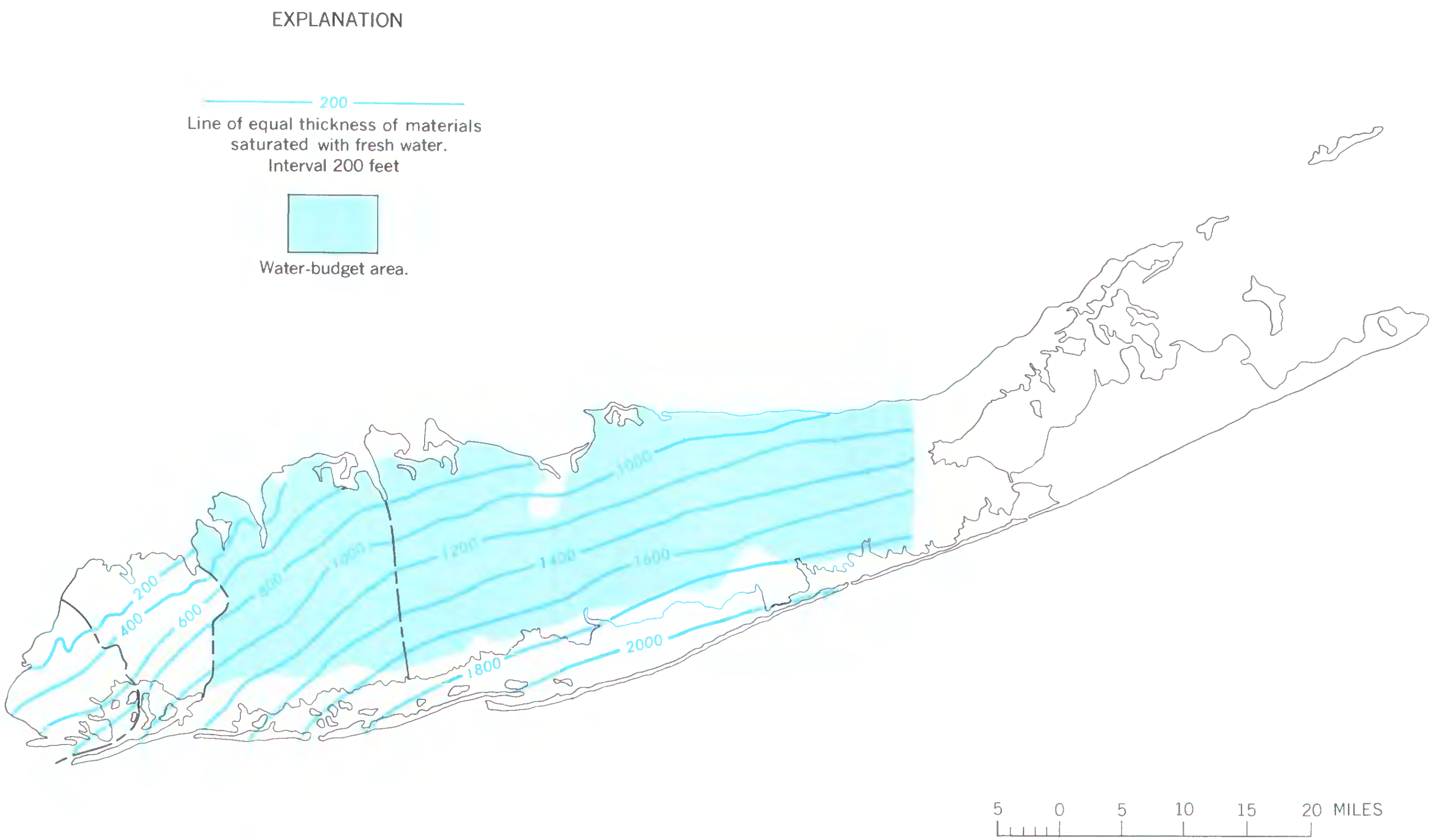
Size of the fresh ground-water reservoir

The fresh ground-water reservoir of Long Island—that is, the unconsolidated rock materials saturated with fresh ground water—ranges in thickness from virtually zero, where bedrock is exposed at the land surface in northwest Queens County, to about 2,000 feet in the south-central part of the island (pl. 2G). The total volume of material saturated with fresh ground water beneath Long Island, excluding that beneath the eastern forks, is nearly 300 cubic miles; the volume beneath the water-budget area is about 180 cubic miles.

The average porosity (the percentage of open spaces in the unconsolidated deposits) probably is about 30 percent. At that assumed porosity, the estimated amount of fresh ground water beneath the water-budget area is about 54 cubic miles, or about 60 trillion (million-millon) gallons. However, the amount of fresh ground water that could be recovered from the fresh ground-water reservoir would be considerably less than the total amount in storage, even if the water levels could be lowered to the base of the reservoir—that is, if the reservoir could be completely "drained". The amount that would be derived from the deposits by gravity drainage (expressed as a percentage of the volume of saturated material and commonly referred to as the "specific yield") would be equal to the total amount in storage minus the amount that is retained in the deposits by capillary, molecular, and other forces. The average specific yield of the ground-water reservoir of Long Island is assumed to be 5–10 percent; therefore, the estimated maximum amount of fresh ground water that would drain from the fresh ground-water reservoir beneath the water-budget area is on the order of 3–6 trillion gallons.

It probably would be impossible to desaturate all of the fresh ground-water reservoir beneath Long Island. Rather, a large part of the fresh ground water removed from storage would be replaced by salty water derived from the ocean. In places, the encroaching salty water might displace the fresh water in front of it, and thereby increase the amount of fresh water derived from storage per unit decrease in ground-water levels. In other places, bodies of fresh ground water could be isolated because of the landward encroachment of tongues of salty water preferentially through the more permeable beds. Locally, this salt-water tonguing might decrease the total amount of fresh ground water that could be moved from storage.

PLATE 2G
SIZE OF THE FRESH
GROUND-WATER RESERVOIR OF
LONG ISLAND, NEW YORK, IN 1965



General relations between fresh and salty ground water

The salty surface water adjacent to Long Island is, for the most part, separated from the fresh ground water by unconsolidated deposits that are filled with salty ground water. These three types of water—fresh ground water, salty ground water, and salty surface water—are hydraulically interconnected, and large amounts of fresh ground water mix with and discharge into the salty waters. The positions of the contacts between the fresh and salty ground waters (sometimes called interfaces), and movement of these contacts are determined largely by differences in the densities and in the hydraulic heads of the waters.

Salty ground water is found in each of the major hydrogeologic units of Long Island. Along the south shore (fig. 2, pl. 2H), the contact between fresh and salty ground water generally is farthest inland in the shallow deposits, and farthest offshore in the deeper deposits. As is the case with the fresh ground water, the salty ground water is under water-table conditions in the shallow deposits, and becomes progressively more confined in the deeper deposits.

In detail (fig. 3, pl. 2H), the contact between the fresh and salty ground water is not sharp; rather, it is gradational. The zone of mixed ground water (part fresh and part salty) is known as the zone of diffusion. Cooper (1964), Kohout (1964), and Lusczynski and Swarzenski (1966) have shown that the movement of water within and near the zone of diffusion is very complex. Presumably, salty ground water moves landward and mixes with the fresh water that is flowing upward and seaward. This in turn, causes a flow of salty surface water from the ocean into the body of salty ground water (fig. 3). Cooper (1964) postulates that this cyclic flow of salty water is a natural feature that occurs in most if not all fresh ground-water reservoirs that are hydraulically connected with the ocean.

For the forks of eastern Long Island (fig. 4, pl. 2H), the relation between fresh ground water, salty ground water, and salty surface (ocean) water is somewhat different than for the main part of the island. At most places on the forks, a well would pass from fresh into salty ground water before it reached the underlying bedrock. In these areas the thickness of the fresh ground-water body is largely related to the difference in density between the fresh ground water and the underlying salty ground water. Mainly because of this difference in density, the fresh ground water usually extends to a depth below the water table roughly equal to 40 times the altitude (above sea level) of the water table at that point. For example, if the water table at a given location is ten feet above sea level, the fresh ground water would be estimated to extend to about 400 feet below sea level.

In detail the relation between fresh ground water and salty ground water on the forks is as complex as elsewhere on Long Island. Salty ground water probably moves landward and mixes with the fresh ground water, and a zone of mixed water (the zone of diffusion) separates the salty and fresh ground water.

PLATE 2H
GENERAL RELATIONS BETWEEN FRESH AND SALTY GROUND WATER ON LONG ISLAND, NEW YORK, UNDER NATURAL CONDITIONS

FIGURE 1. Locations of sections A–A′ and B–B′.

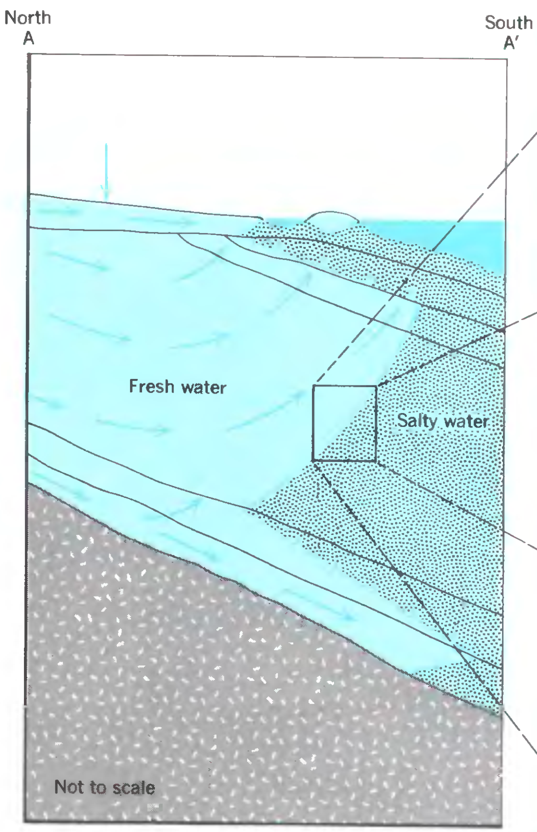


FIGURE 2. Generalized boundaries between fresh and salty ground water, and natural movement of water along the south shore of Long Island.

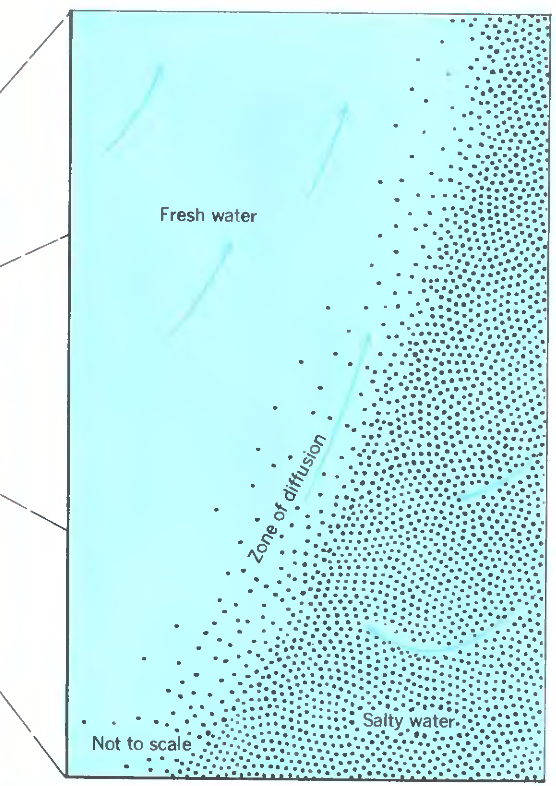


FIGURE 3. Movement of water in and near the zone of diffusion, which separates fresh ground water from salty ground water. (Adapted from Cooper, 1964, fig. 2.)

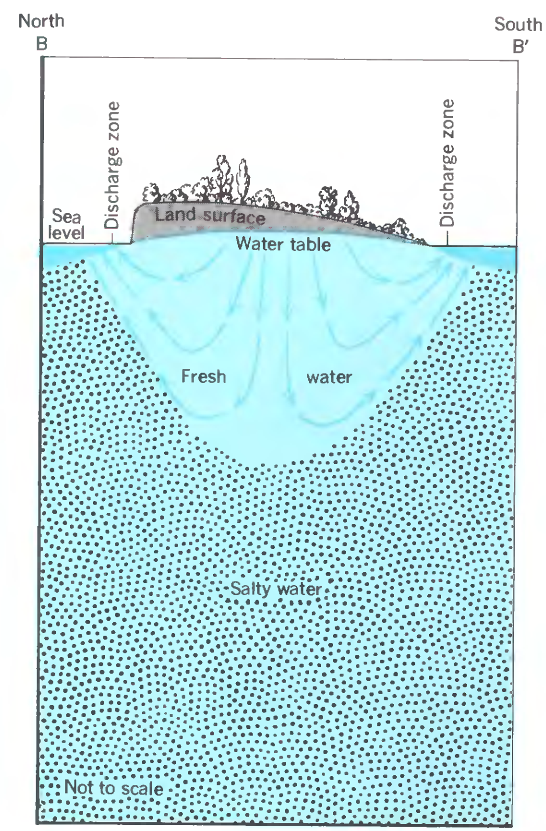


FIGURE 4. Generalized boundaries between fresh and salty ground water, and natural movement of water on the forks of eastern Long Island.

3 WHERE THE WATER COMES FROM

Average annual precipitation

Under natural or predevelopment conditions, precipitation (mainly rain and snow) was the source of all of Long Island's fresh water. Contrary to a former widely held misconception, "underground streams" have never brought fresh water from the mainland to Long Island.

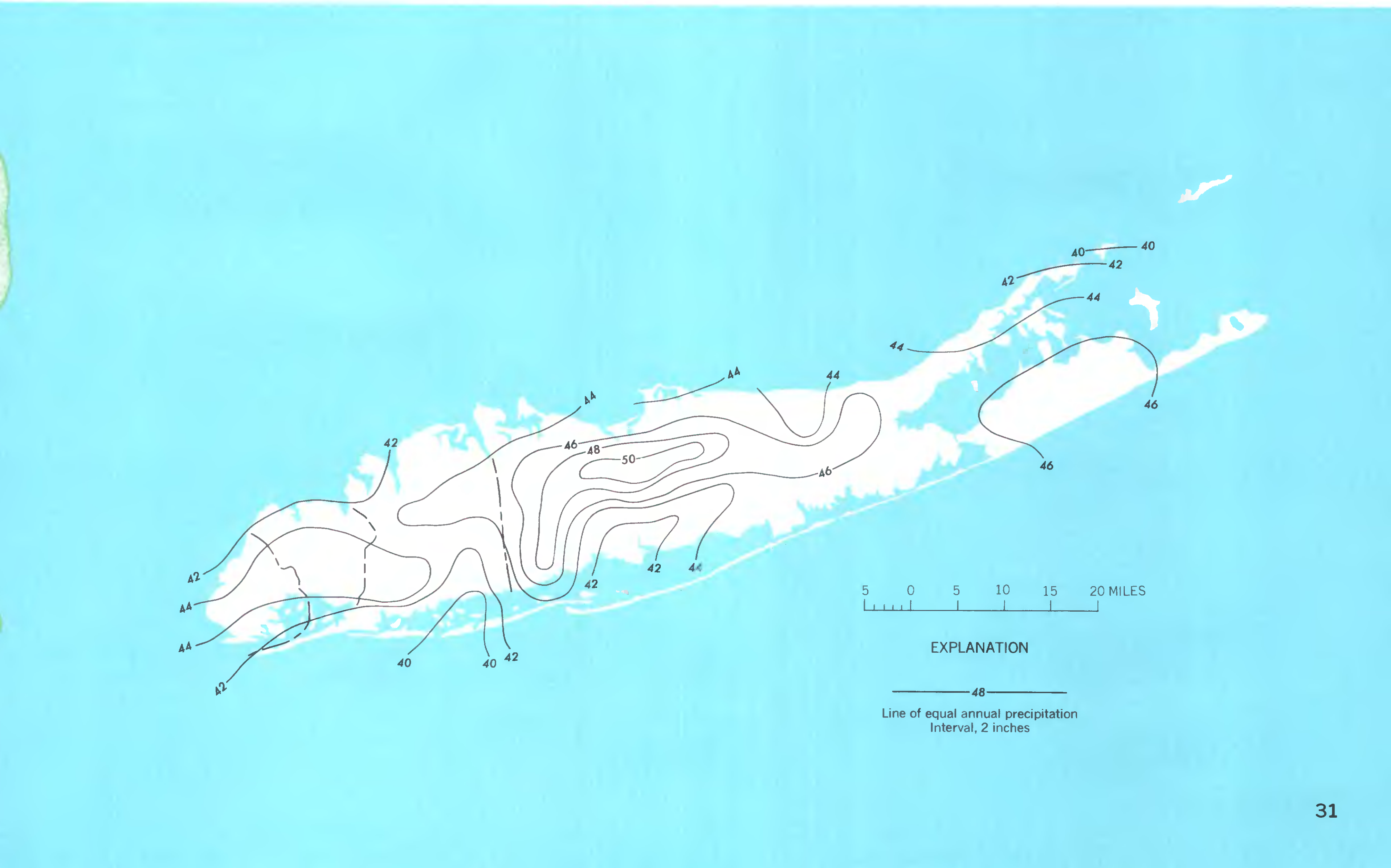
Plate 3A shows contours of average annual precipitation for Long Island for the period of water years 1951–65. This 15-year period was selected because of the availability of comparable data at the 46 stations used as control points for the preparation of the map. Fortunately, the precipitation data for the 15-year period are reasonably comparable to the long-term data available from a few stations; therefore, the averages can be applied with considerable confidence to the longer index period (water years (1940–65).

It is evident from the map that precipitation on Long Island varies considerably from place to place. The maximum average annual precipitation, about 51 inches, occurs in about the middle of the island, in the Lake Ronkonkoma area. The minimum average annual precipitation, about 40 inches, occurs along the coast in southern Nassau County and on Plum Island.

The greater average annual precipitation tends to occur along the east-west axis of Long Island, roughly parallel to and in many places coinciding with the ridge of east-west trending hills. Apparently, differential heating and greater roughness of the land as compared to the ocean, and perhaps the higher altitude of the hills, cause a significant uplift of the air moving across Long Island. This upward movement causes the air to cool, thereby decreasing its capacity to retain moisture and increasing the amount of precipitation.

Average annual precipitation on the water-budget area for water years 1951–65 (as computed from plate 3A) is about 44 inches. This is equivalent to an average of about 2.1 mgd (million gallons per day) per square mile, or about 1,600 mgd for the water-budget area.

PLATE 3A
AVERAGE ANNUAL PRECIPITATION ON LONG ISLAND, NEW YORK, WATER YEARS 1951-65
(Generalized from an unpublished map prepared by the U.S. Weather Bureau, 1967.)



Average monthly precipitation

The long-term monthly precipitation on Long Island averages about 3.7 inches. For individual months, it ranges from a low of about 2.5 inches to a high of nearly 5 inches. In general, the precipitation is distributed fairly evenly throughout the year—there is no distinctly wet or dry season (pl. 3B). Moreover, as shown on the accompanying graphs, seasonal variations in precipitation are nearly the same from place to place on Long Island.

The greatest average monthly precipitation occurs in August, because this is the month during which tropical hurricanes most often reach Long Island. Although such storms generally occur only once every few years, the very large quantities of precipitation associated with them (occasionally more than 10 inches of rain falls in a day or two) significantly affect the average monthly values.

During the winter, most of the precipitation on Long Island is derived from regional storms that originate in the Gulf of Mexico and in the southwestern part of the North Atlantic Ocean. In the summer, however, most of the precipitation is associated with local thunderstorms. On the average, the lowest monthly precipitation occurs in June—a month of transition between the period when regional storms predominate and the period when local thunderstorms supply most of the precipitation.

Even though the average monthly precipitation on Long Island is fairly uniform, precipitation values for specific months range widely. For example, the maximum monthly precipitation recorded at LaGuardia Airport was 16.05 inches in August 1955, whereas the minimum monthly value recorded at the same station was 0.06 inch in October 1963.

A recording rain gage.

PLATE 3B

AVERAGE MONTHLY PRECIPITATION AT FIVE STATIONS ON LONG ISLAND, NEW YORK, WATER YEARS 1950-64

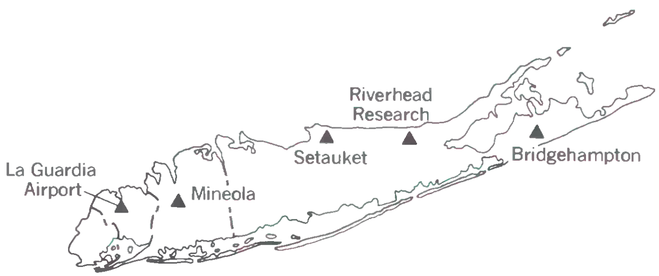


FIGURE 6. Location of precipitation-measuring stations.

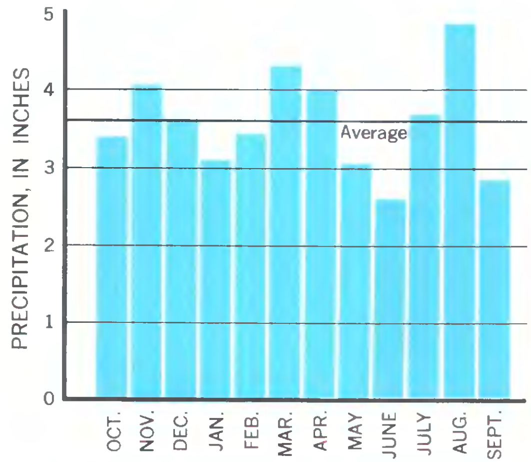


FIGURE 1. Average monthly precipitation at La Guardia Airport.

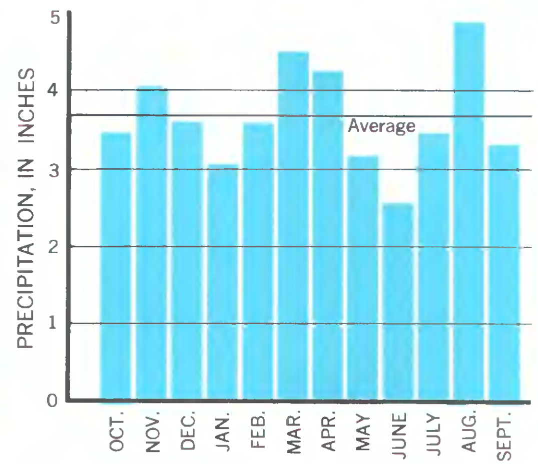


FIGURE 2. Average monthly precipitation at Mineola.

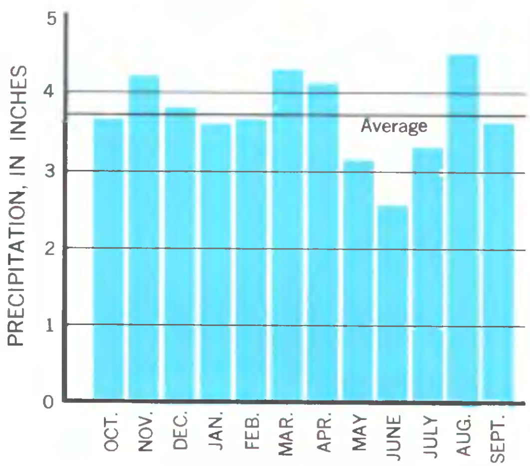


FIGURE 3. Average monthly precipitation at Setauket.

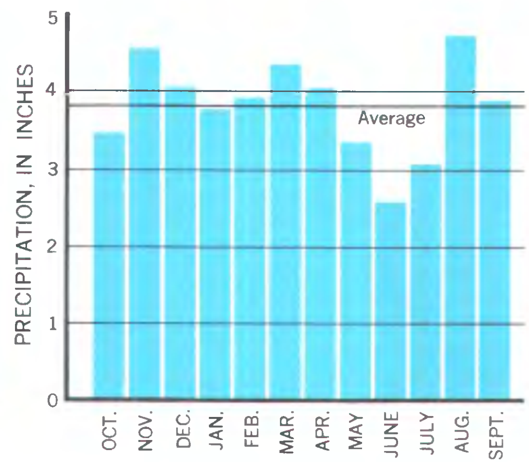


FIGURE 4. Average monthly precipitation at Riverhead Research Laboratory.

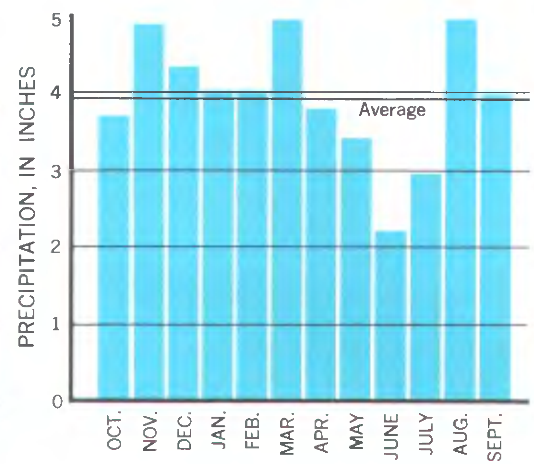


FIGURE 5. Average monthly precipitation at Bridgehampton.

Long-term variations in precipitation at Setauket

Data obtained at Setauket, near the north shore in Suffolk County (pl. 3B), provide one of the longest continuous records of precipitation on Long Island. As shown in figure 1 of plate 3C, the annual precipitation ranges widely, from a maximum of 56.4 inches in water year 1898 to a minimum of 31.9 inches in water year 1965. The long-term average annual precipitation at Setauket is 44.6 inches.

The slope of the graph showing cumulative departure from average precipitation in figure 2 of plate 3C indicates whether precipitation in a given year or in several successive years was above or below average. An upward slope to the right indicates above-average precipitation, whereas a downward slope to the right indicates below-average precipitation. During the severe drought period of water years 1962–65, a cumulative deficiency of about 28 inches of precipitation was recorded at Setauket—the largest deficiency for a continuous sequence of years for the period of record. The second largest deficiency, about 23 inches, occurred in the 3-year period, water years 1909–11.

The odds that a given amount of precipitation will occur in any single year can be estimated from figure 3 of plate 3C. For example, the chances are that 80 percent of the time, or in 8 out of every 10 years, the annual precipitation at Setauket will be equal to or greater than 39 inches. On the other hand, the chances are that the annual precipitation will be equal to or greater than 49 inches in only 2 out of every 10 years. The odds against the annual precipitation being as little as 31.9 inches, as it was in water year 1965, are nearly 100 to 1.

PLATE 3C

LONG-TERM VARIATIONS IN PRECIPITATION AT SETAUKET, LONG ISLAND, NEW YORK, WATER YEARS 1887–1965

(Data from records of the U.S. Weather Bureau.)

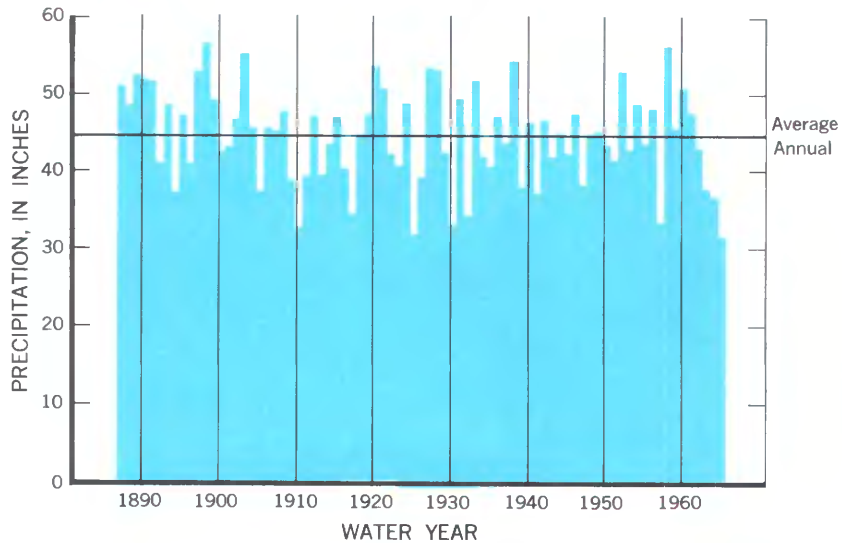


FIGURE 1. Annual precipitation.

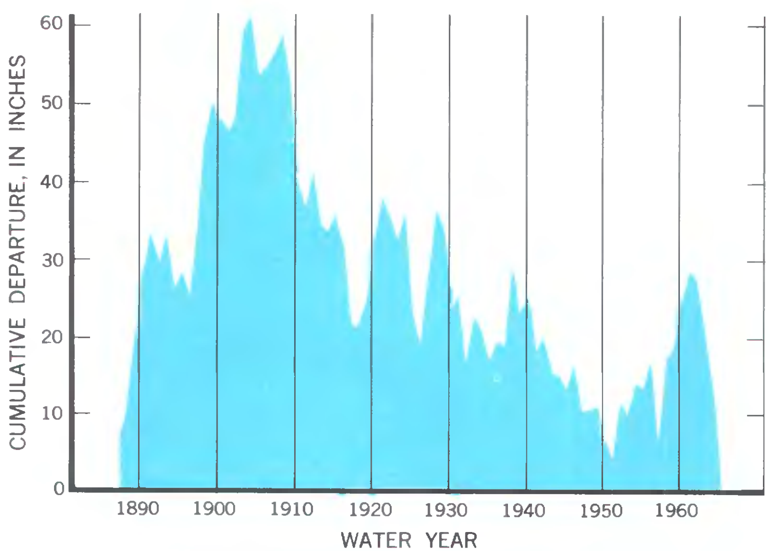


FIGURE 2. Cumulative departure from average precipitation.

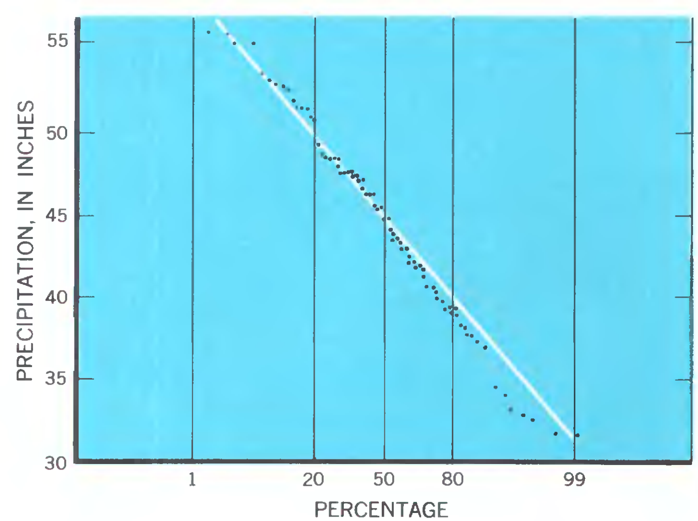


FIGURE 3. Percentage of time that various values of annual precipitation were equaled or exceeded.

4 WHERE THE WATER GOES

The natural elements of discharge from the hydrologic system of Long Island are considered in this section of the report. Discharge resulting from the activities of man is considered in chapter 7.

Evapotranspiration of precipitation

The term "evapotranspiration" refers to all the natural processes by which water on and beneath the land surface is returned to the atmosphere as water vapor. On Long Island, the major elements of evapotranspiration are (a) evapotranspiration of precipitation soon after it falls, (b) evaporation from permanent or semipermanent surface-water bodies, and (c) evapotranspiration of ground water.

Evapotranspiration of precipitation soon after it falls represents the largest element of fresh-water discharge (either natural or artificial) from the hydrologic system of Long Island. This type of evapotranspiration mainly included (1) evaporation from vegetation and land surfaces that have been wetted by precipitation, and (2) transpiration from the zone of aeration of moisture derived directly from precipitation but not from the underlying zone of saturation. The term "soon after it falls" is necessarily somewhat indefinite; the period of time involved may range from a few minutes, as in the case of evaporation of rain from a warm land surface, to several months, as can be the case of transpiration of soil water from the zone of aeration. "Evapotranspiration of precipitation soon after it falls" specifically excludes evapotranspiration of moisture derived from the ground-water reservoir as well as evaporation from surface-water bodies.

Sufficient data are not available to directly evaluate evapotranspiration of precipitation with a high degree of accuracy. However, the writers have developed empirical estimates based mainly upon a method described by Thornthwaite and Mather (1957). The estimated annual evapotranspiration of precipitation from the water-budget area for the index period (water years 1940–65) ranged from a high of about 26 inches in water year 1946 to a low of about 12 inches in 1965 (fig. 1, pl. 4A). The estimated average annual evapotranspiration of precipitation for the index period was nearly 21 inches, which is equivalent to an average of about 760 mgd. Accordingly, on the average, about 46 percent of the precipitation on the water-budget area of Long Island is consumed by evapotranspiration soon after it falls. This estimate is in line with an estimate of about 50 percent made by Spear in 1912 and subsequently adopted by later investigators.

As is to be expected, the amount of precipitation consumed by evapotranspiration in a given year is closely related to the total precipitation in that year. For example, during the severe drought period of water years 1963–65, when the cumulative precipitation deficiency at Setauket was about 28 inches below average (fig. 2, pl. 3C), the estimated 3-year evapotranspiration of precipitation was nearly 18 inches below average (fig. 2, pl. 4A). The odds against evapotranspiration of precipitation being as low as it was in water year 1965 are similar to those for precipitation—nearly 100 to 1 (fig. 3, pl. 4A).

The estimated average annual rate of evaporation from open bodies of surface water on Long Island is 34 inches, based on evaporation-pan measurements made at Mineola in 1949–60 (Pluhowski and Kantrowitz, 1964, p. 28–29). However, inasmuch as the surface area of fresh ponds, lakes, and streams on Long Island is small, the average annual evaporation from them, if distributed over the water-budget area, would amount to a small fraction of an inch, and is negligible in terms of the overall water budget.

Evapotranspiration of ground water, the third major element of evapotranspiration, is considered in a subsequent part of the atlas (p. 46).

PLATE 4A

VARIATIONS IN ESTIMATED EVAPOTRANSPIRATION OF PRECIPITATION ON LONG ISLAND, NEW YORK, WATER YEARS 1940-1965

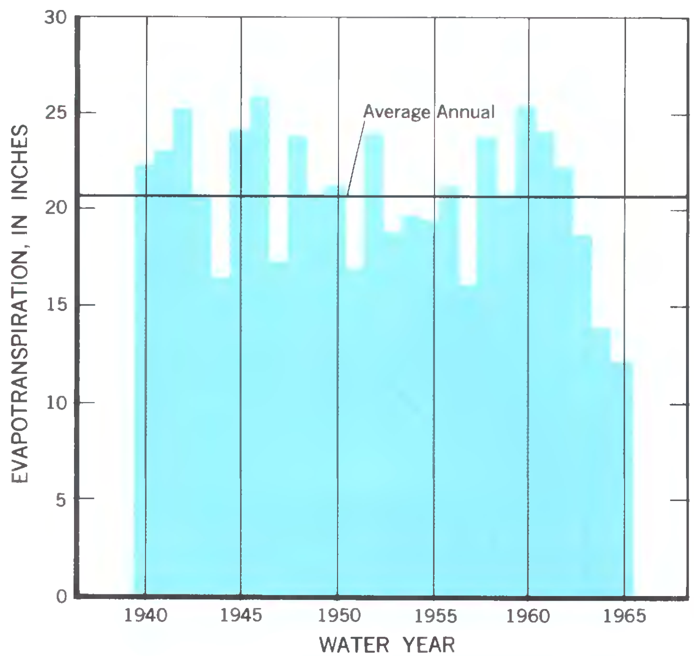


FIGURE 1. Annual evapotranspiration.

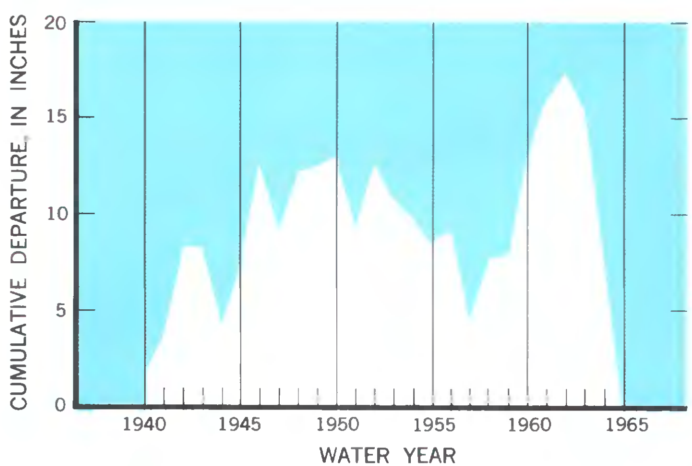


FIGURE 2. Cumulative departure from average evapotranspiration.

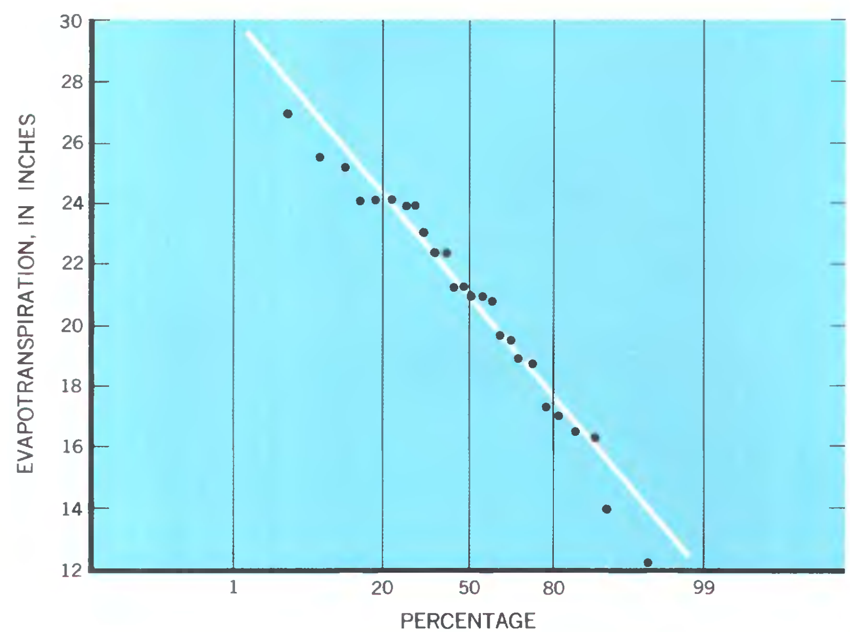


FIGURE 3. Percentage of time that various values of annual evapotranspiration were equaled or exceeded.

Streamflow to the sea

Streams flowing to the sea represent another major element of fresh-water discharge from the hydrologic system of Long Island. Continuous streamflow records, ranging in length from about 15 to 30 years, are available for the 19 streams shown on plate 2B. The gaging (streamflow-measuring) stations on these streams were established at points sufficiently upstream from the ocean, bays, and Long Island Sound so that the records would not be affected by tidal fluctuations. The data obtained at these stations, therefore, are indicative only of the flows in the streams that discharge from the water-budget area into the tidal reaches, and are not indicative of the total streamflow leaving Long Island.

The combined average flows (at the gaging stations) of the 19 streams in water years 1940–65, ranged from 208 cfs in 1965 to 401 cfs in 1956, and averaged about 300 cfs for the 26-year period (fig. 1, pl. 4B). Sawyer (1958, p. 225–226; and 1961, p. 96–98) estimated that the flows of the 19 streams on which continuously recording gaging stations are located, plus the flows of the streams for which only partial records (several individual measurements per year) are obtained, represent 90–95 percent of the strictly fresh-water streamflow from Long Island. Sawyer also estimated (written communication, 1966) that the combined flows of the streams for which only partial records are available is equal to about 55 percent of the combined flows of the 19 major streams. On the basis of these relations, the average annual streamflow that discharged from the water-budget area during the period of water years 1940–65 is estimated to be about 520 cfs, or about 340 mgd.

Streamflow on Long Island was below average in 7 of the first 8 years of the index period 1940–65 (fig. 2, pl. 4B). It was above average in 9 years of the 11-year period of water years 1952–62, and was considerably below average during the drought years of 1963–65.

Statistically, the chances are that the record-low flows that occurred in water year 1965 will not recur more than about once in a hundred years (fig. 3, pl. 4B). On the other hand, the chances are that the highest flows that occurred during the index period, an average total for the 19 streams of about 401 cfs in water year 1956, will occur about 3 percent of the time or on the average be repeated about once in every 30 years. Over a long period of years, the chances are that the combined annual flows of these streams at the gaging stations will average at least 300 cfs about half the time.

The streamflow discharging from the water-budget area is not the total streamflow entering salty water along the shores adjacent to the water-budget area. Particularly along the south shore, considerable quantities of fresh ground water seep into the estuarine reaches of the streams downstream from the gaging stations or partial-record sites. In the Babylon-Islip area, Pluhowski and Kantrowitz (1964) estimated this quantity of seepage to be 25–30 percent of total streamflow discharging to salty water.

One of the major features of the hydrology of Long Island is the fact that about 95 percent of the streamflow, about 320 mgd, is derived from the ground-water reservoir, and only about 5 percent is direct (overland) runoff. (See Pluhowski and Kantrowitz, 1964, p. 35.)

PLATE 4B
STREAMFLOW OF 19 MAJOR STREAMS
ON LONG ISLAND, NEW YORK
WATER YEARS 1940–1965

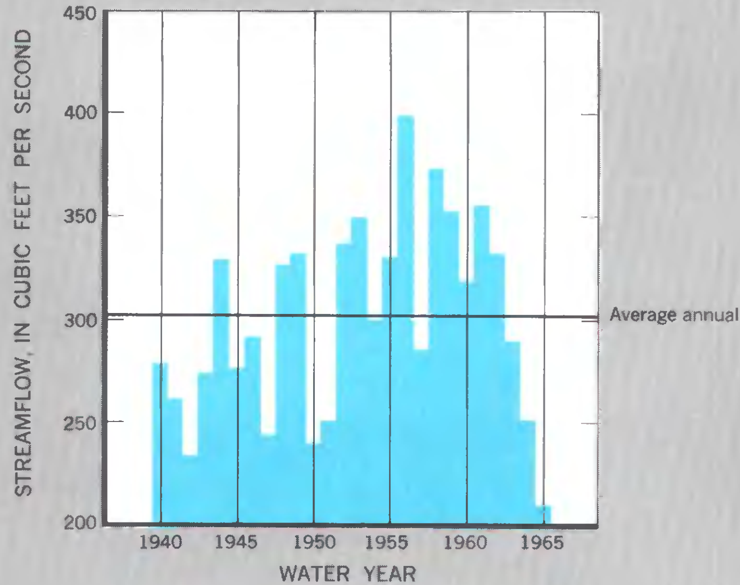


FIGURE 1. Annual streamflow

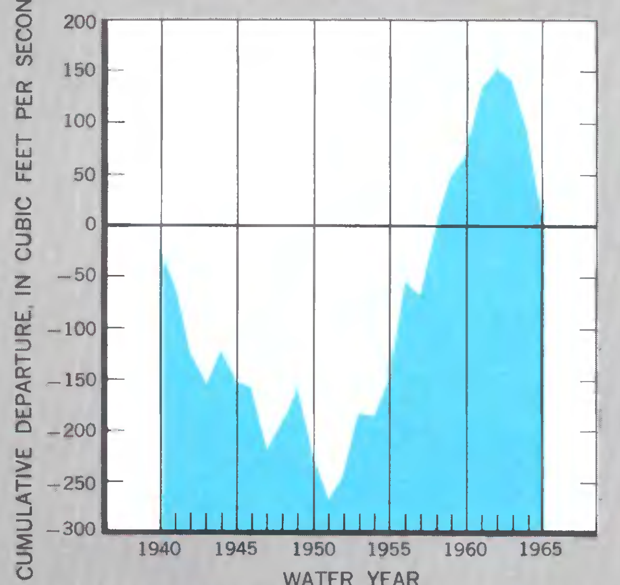


FIGURE 2. Cumulative departure from average annual streamflow.

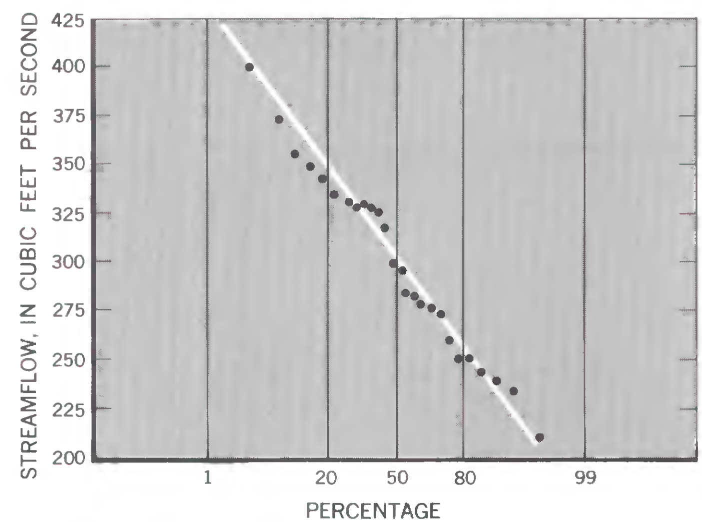


FIGURE 3. Percentage of time that various values of annual streamflow were equaled or exceeded.

Direct runoff

Direct runoff is the water that flows into streams from the land surface promptly after rainfall or snowmelt. In many parts of the nation, direct runoff is a major percentage of the annual streamflow. Moreover, in many areas direct runoff commonly causes serious flooding and associated economic and other losses. On Long Island, however, direct runoff normally is only a small part of the annual streamflow, and flooding caused by direct runoff usually is negligible.

Direct runoff commonly is estimated from a streamflow hydrograph—a graph showing variations of discharge with time. A method of analyzing a hydrograph of this type is described by Pluhowski and Kantrowitz (1964, p. 31). The accompanying graph (fig. 2, pl. 4C) shows the average daily discharge (the upper line), the estimated direct runoff (the shaded area), and the estimated ground-water contribution, or base flow (the lower line) of Champlin Creek.

The relation between precipitation measured at the Brentwood station and direct runoff in the drainage basin of Champlin Creek, for 10 selected storms, is shown in figure 3 on the accompanying plate (pl. 4C). On the average, the percentage of precipitation reaching Champlin Creek by direct runoff decreased as the total storm rainfall decreased. For example, when precipitation totalled 10 inches, about 6 percent entered Champlin Creek as direct runoff, and for storms of 2 to 3 inches of precipitation, direct runoff to Champlin Creek was equal to only about 2 percent of the total rainfall.

Pluhowski and Kantrowitz (1964, p. 35) calculated that the average ratio of direct runoff to total streamflow for all streams in the Babylon-Islip area (southwestern Suffolk County) was about 4.7 percent. Locally, urbanization has increased the percentage of direct runoff to some streams on Long island, but the total increase is negligible compared to the total direct runoff on Long Island. Therefore, because the Babylon-Islip area is reasonably representative of much of the water-budget area, the direct runoff to streams for the index period (water years 1940–65) is estimated to be 5 percent of the total streamflow, or nearly 20 mgd.

FIGURE 1. Location of Champlin Creek and the Brentwood precipitation station

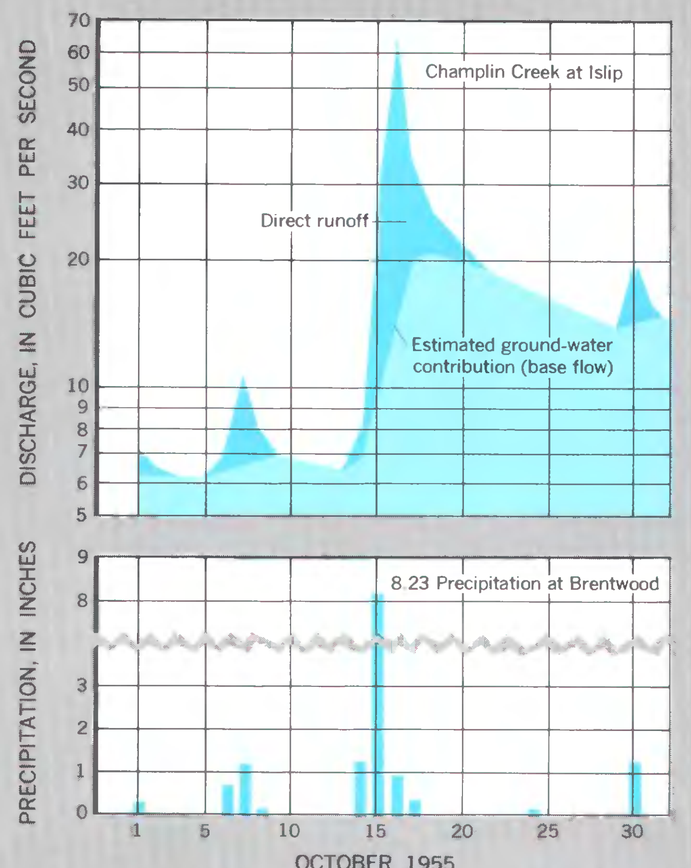


FIGURE 2. Discharge of Champlin Creek at Islip, and daily precipitation at Brentwood, October 1955

PLATE 4C

DIRECT RUNOFF IN THE CHAMPLIN CREEK AREA

LONG ISLAND, NEW YORK

(After Pluhowski and Kantrowitz, 1964, figs. 7 and 8.)

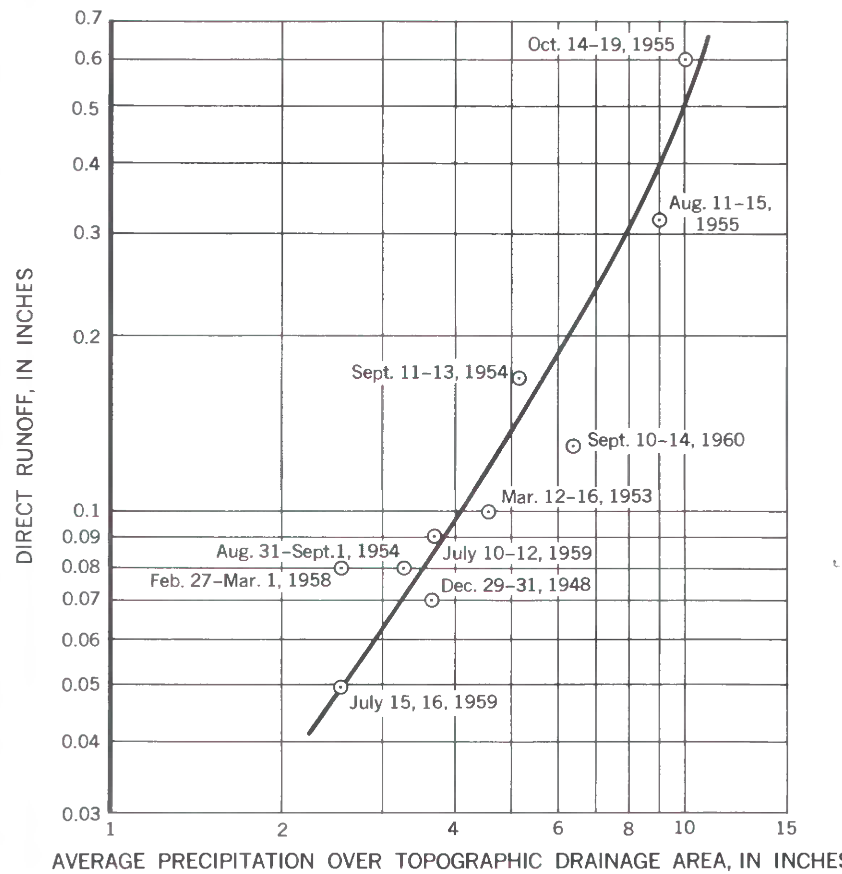


FIGURE 3. Relation of direct runoff in Champlin Creek to average precipitation for severe storms, 1948-1960.

Average monthly streamflow

Monthly streamflow data for five representative streams on Long Island are shown on plate 4D. Usually, the maximum flows for these streams occur in March or April, and the minimum flows occur in September or October. For all 19 major streams on Long Island, the combined monthly flows are normally greatest in April (average 374 cfs) and least in September (average 251 cfs). The relation between these combined average flows for the two months indicates that the total outflow of fresh water in the streams during the month of greatest flow averages about 1.5 times the total during the month of least flow.

As shown on plate 4D, the relation between the maximum monthly flows of individual streams differs considerably from stream to stream. For example, the average monthly flow of Nissequogue River (fig. 2) is 1.2 timès larger during the month of greatest average (March) than during the month of lowest average (October); whereas, the average monthly flow of Peconic River (fig. 5) is almost 2 times larger during corresponding months.

Differences in the range of monthly flows of Long Island's streams are related to differences in the degree of artificial control of the flows of the various streams; they are also related to differences in the sizes of and conditions within the areas that contribute ground water to the streams. Despite the fact that the maximum monthly flows in some of Long Island's streams are, on the average, nearly twice the minimum monthly flows, the difference between the monthly flows for all the streams is remarkably small in comparison to streams elsewhere. This comparative uniformity of monthly flows mainly reflects the relation between the streams and the ground-water reservoir, which is described elsewhere in this atlas. (See p.62.)

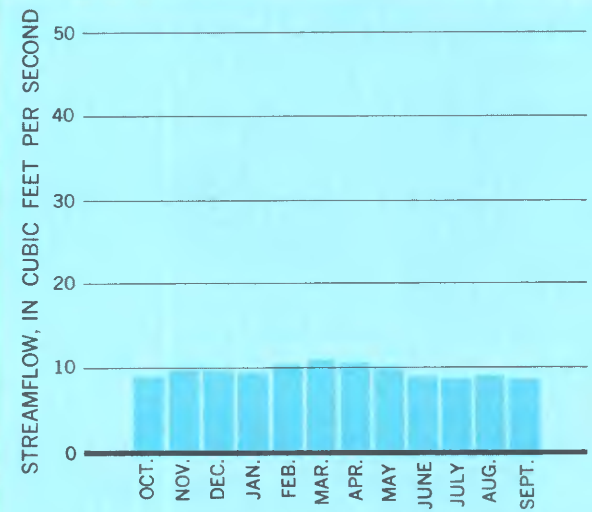


FIGURE 1. Average monthly streamflow of Mill Neck Creek.

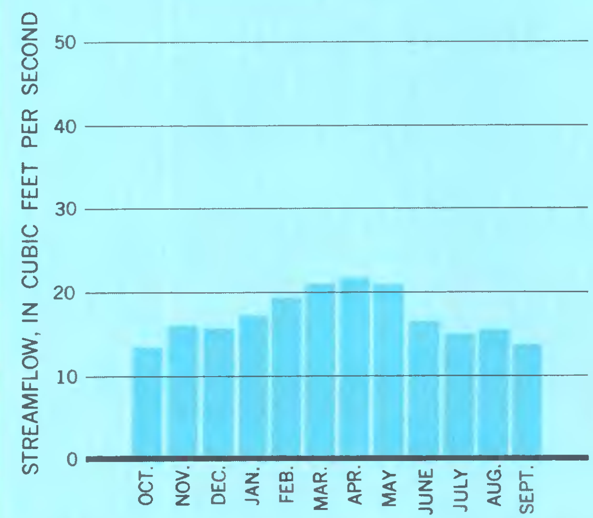


FIGURE 3. Average monthly streamflow of East Meadow Brook.

PLATE 4D
AVERAGE MONTHLY STREAMFLOW
OF FIVE STREAMS ON LONG ISLAND
NEW YORK, WATER YEARS 1940-1965

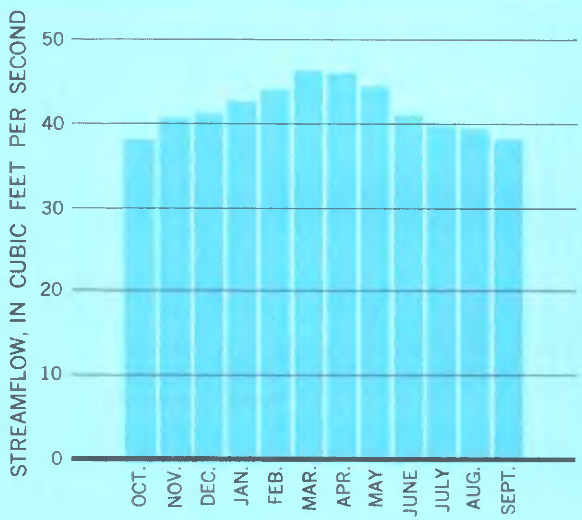


FIGURE 2. Average monthly streamflow of Nissequogue River.

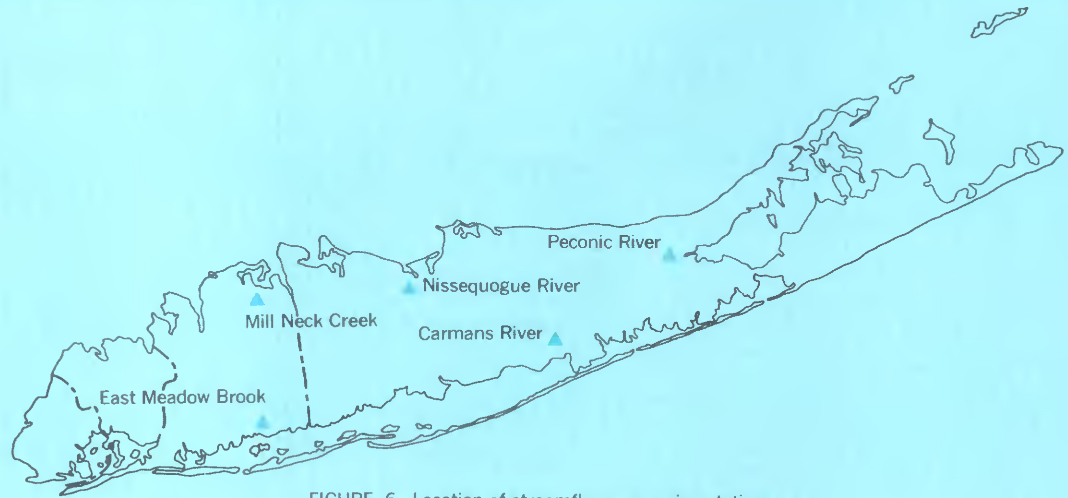


FIGURE 6. Location of streamflow-measuring stations.

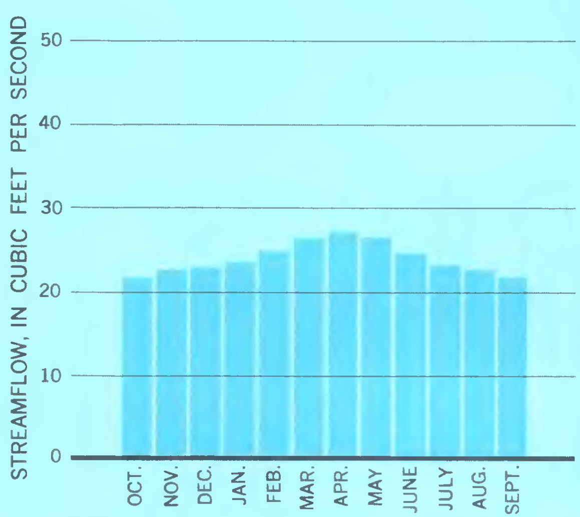


FIGURE 4. Average monthly streamflow of Carmans River.

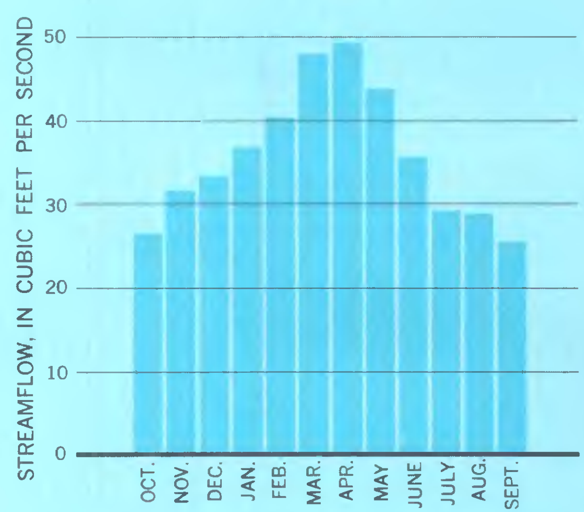


FIGURE 5. Average monthly streamflow of Peconic River.

Ground-water recharge

A substantial quantity of precipitation infiltrates into the ground and recharges the ground-water reservoir. Sufficient data are not available to directly estimate the quantity of ground-water recharge on Long Island; however, an indirect estimate of ground-water recharge in the water-budget area can be developed based on the relation that, under natural conditions, recharge was equal to total precipitation minus evapotranspiration of precipitation, minus direct runoff. In other words, the precipitation that was not consumed by evapotranspiration and did not flow to the sea by direct runoff recharged the ground-water reservoir.

If it is assumed that recharge in the water-budget area during the index period (water years 1940–65) was the same as it would have been under natural conditions, then recharge for this period can be estimated by subtracting, from the precipitation that occurred in that period, (a) the evapotranspiration data shown on plate 4A, and (b) an appropriate value for direct runoff. The recharge estimates shown on plate 4E were derived in this manner; the precipitation values used were those obtained at Mineola (where the recorded precipitation was approximately equal to the average for all Long Island), and a value of 1 inch per year was used for direct runoff.

The estimates of ground-water recharge in the water-budget area range from a high of about 33 inches in 1958 to a low of 12 inches in 1950, and average nearly 23 inches, or about 820 mgd, for the 26-year index period (fig. 1, pl. 4E). As is to be expected, years of above- and below-average recharge generally correspond with years of above- and below-average precipitation, respectively. However, as is evident from a comparison of the data in plates 3C and 4E, the correlation between precipitation and recharge is not simple.

The simplifying assumptions used to make the empirical estimates of recharge should not be overlooked. Moreover, the effects of the activities of man, which in some places have increased and in other places have decreased recharge, are intentionally not considered in the recharge estimates shown in plate 4E, mainly because information is not available to accurately assess the quantitative impact of these activities. Accordingly, it is possible that the individual estimates of annual recharge may be in error by as much as 25–50 percent, but it is believed that the estimate of average annual recharge probably is accurate at least within plus or minus 25 percent.

PLATE 4E
VARIATIONS IN ESTIMATED
GROUND-WATER RECHARGE
ON LONG ISLAND, NEW YORK
WATER YEARS 1940–1965

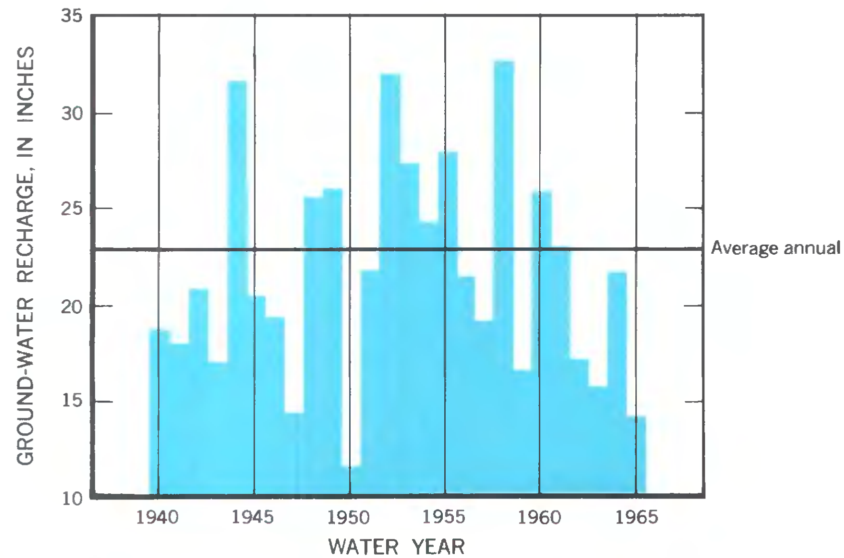


FIGURE 1. Annual ground-water recharge.

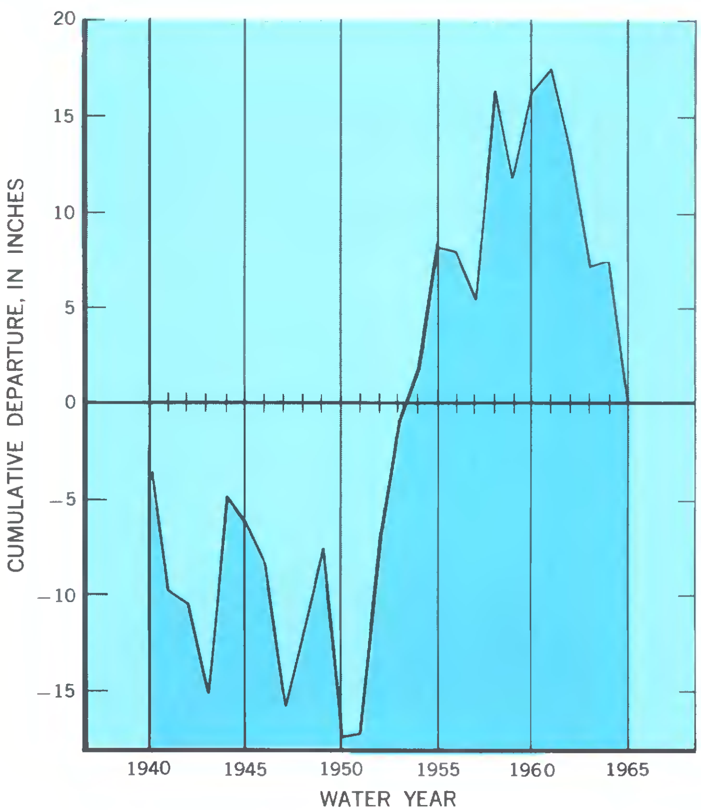


FIGURE 2. Cumulative departure from average annual ground-water recharge.

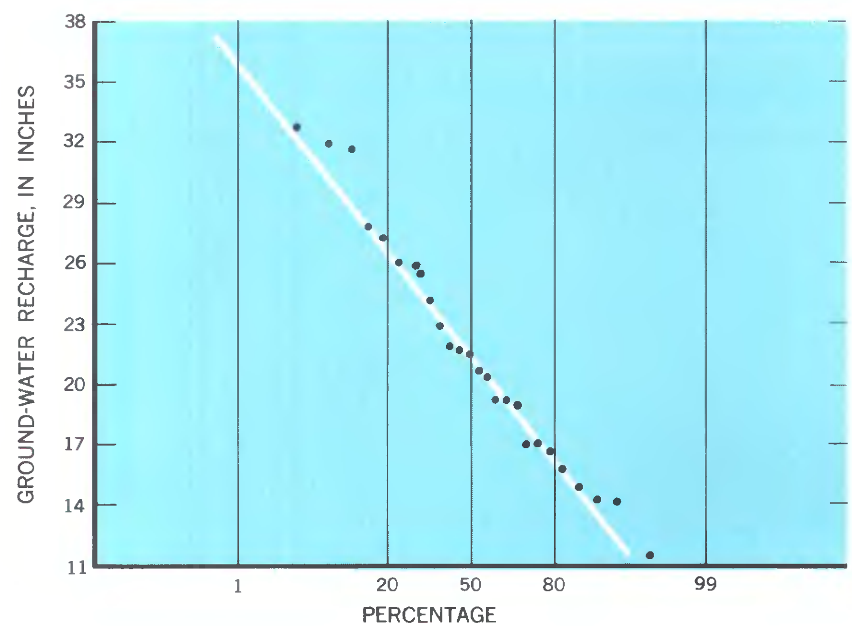


FIGURE 3. Percentage of time that various values of annual ground-water recharge were equaled or exceeded.

Ground-water movement and discharge

Ground water beneath the surface of Long Island is in constant motion, flowing from areas of higher to areas of lower hydraulic head. Under natural conditions, the rate of ground-water flow in the horizontal direction through the more permeable materials on Long Island ranged from a few feet to perhaps a few hundred feet per year. The flow in the vertical direction was on the average much slower—probably on the order of a hundred to a thousand times slower—because of the many relatively impermeable layers in the various formations (indicated diagrammatically on plates 2C and 2D) through which the water had to flow. Accordingly, much of the fresh water presently being discharged from the ground-water system of Long Island (especially from the deeper parts) has been moving through the system for hundreds or even thousands of years.

As noted previously, the horizontal direction of ground-water movement can be deduced from water-level contour maps. The overall shape of the water table in Nassau and Suffolk Counties under natural conditions was similar to that shown in plate 2E. Therefore, the horizontal direction of ground-water movement in these counties under natural conditions was mainly northward and southward toward the shores from a ground-water divide near the center of the island.

Under natural conditions, more than half the water that reached the water table and recharged the ground water moved laterally through the upper glacial aquifer and ultimately discharged into streams or into salt-water bodies bordering Long Island (pl. 4F). The remainder of the natural recharge water moved downward into the deeper artesian aquifers and thence laterally toward the sea. As indicated by the arrows on plate 4F, which show the general pattern of movement through the ground-water reservoir, the recharge areas of the Lloyd aquifer in the water-budget area are in the north-central part of Long Island corresponding to the areas of highest elevation of the water table (pl. 2E), and recharge to the deeper zones of the Magothy aquifer occurs mainly in those areas as well as immediately adjacent areas.

The estimated average natural discharge of ground water from the upper glacial aquifer into the streams within the water-budget area is 320 mgd—340 mgd total streamflow minus 20 mgd direct runoff. The other major elements of natural ground-water discharge were subsurface outflow from the water-budget area, spring flow, and ground-water evapotranspiration. Subsurface outflow under natural conditions mainly included the subsurface movement of ground water northward to Long Island Sound, and southward (a) to the swampy lowlands bordering the south-shore bays, (b) directly into the bays, and (c) directly into the Atlantic Ocean. A small and probably negligible quantity of subsurface flow discharged westward into Queens County and eastward toward the forks.

Sufficient data are not available to directly estimate the largest element of natural ground-water discharge from the water-budget area—subsurface outflow. However, an indirect method based on water-budget concept suggests that total subsurface outflow from the water-budget area under natural conditions was on the order of 470 mgd (p. 58).

Spring flow in the budget area was negligible except along the north shore, where it probably averaged 15 mgd or less and discharged almost directly into the sound. Evapotranspiration of ground water within the budget area also probably averaged about 15 mgd.

EXPLANATION

TYPES OF GROUND-WATER DISCHARGE

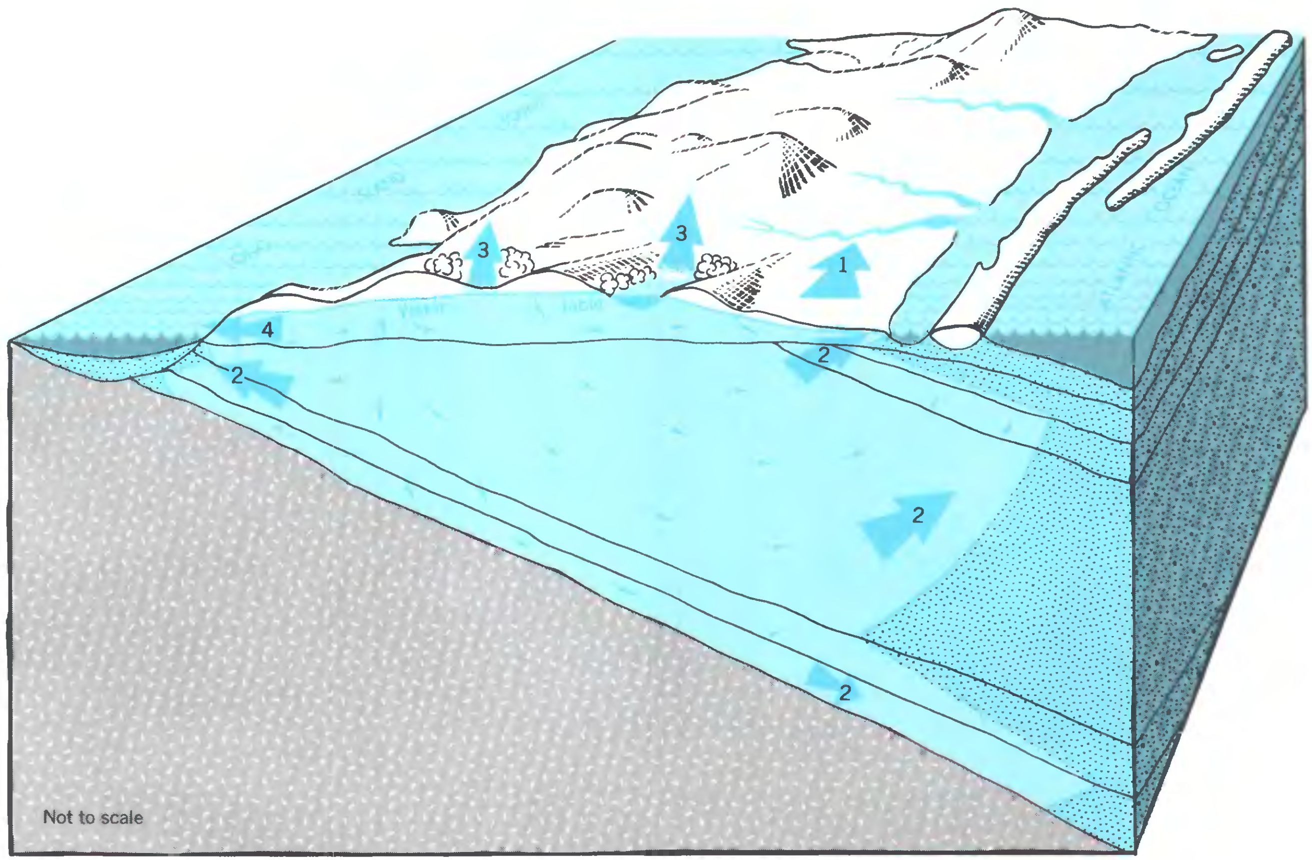
1 Seepage to streams
2 Subsurface outflow
3 Evapotranspiration
4 Spring flow

General movement of fresh ground water

Fresh ground water

Salty ground water

PLATE 4F
GROUND-WATER MOVEMENT AND DISCHARGE ON LONG ISLAND, NEW YORK, UNDER NATURAL CONDITIONS



5 CHEMICAL AND PHYSICAL PROPERTIES OF THE WATER

Changes in the chemical quality of the water under natural conditions

Most of the significant chemical properties of water are related to the substances that are in solution therein. One of the common units used to express dissolved-solids content is the part per million (ppm), which is a measure of the number of parts, by weight, of dissolved material in one million parts of the water solution containing the dissolved material.

Practically all the elements and compounds above, on, and beneath the surface of Long Island are, at least to some extent, soluble in water. Therefore, all of Long Island's water contains at least some dissolved solids. In addition, the dissolved-solids content of the water commonly increases as the water moves through the system.

The general flow pattern in the hydrologic system of Long Island and related water-quality features under natural conditions are shown on the accompanying diagram (pl. 5A). Changes in quality related to the activities of man are described later in the report. Under natural conditions, as air moved across the bodies of salty water bordering Long Island, it picked up small quantities of common salt ($NaCl$) and other substances from the salty spray (item 1 of pl. 5A). Some of these substances were in the precipitation that fell on the island. In addition, particles of dust and gases from the atmosphere were incorporated in the precipitation as it formed in the atmosphere and as it fell to earth (item 2).

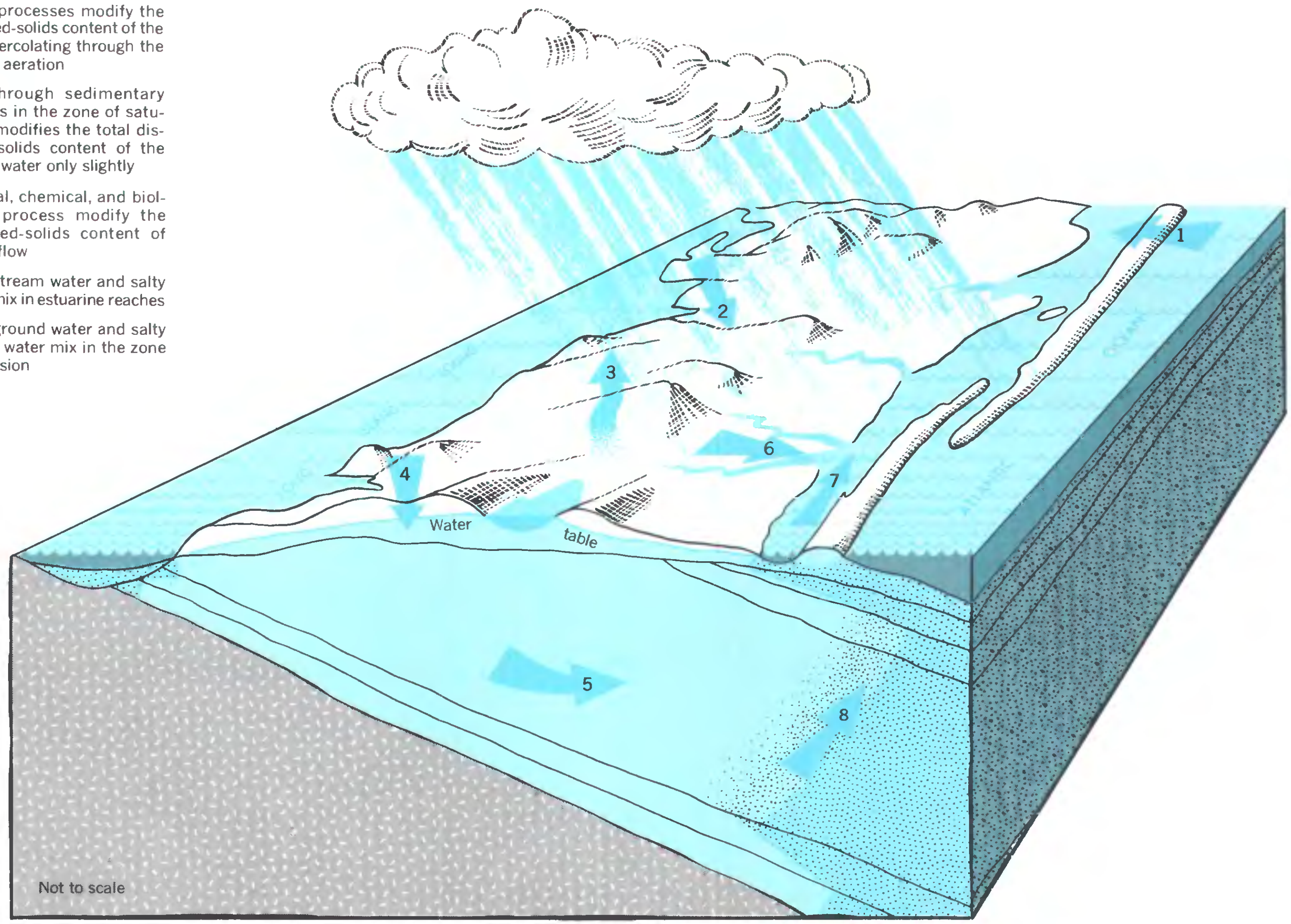
Evaporation from the land surface and from the soil zone, and transpiration by plants, increased the dissolved-solids content of the precipitation after it reached the ground (item 3). As the water that originated as precipitation moved through the uppermost part of the zone of aeration (item 4), it came into contact with and partly dissolved compounds that were formed in the biologically and chemically active soil zone. After passing through the soil zone, the water continued, but at a slower rate, to dissolve additional substances from the remainder of the less chemically active zone of aeration.

In general the dissolved-solids content of the water continued to increase as the water moved into and through the zone of saturation (item 5). Most of the materials in the zone of saturation are moderately to highly insoluble in water. Accordingly, the dissolved-solids content of the ground water generally increased only slightly as it moved through this zone.

Some of the ground water ultimately discharged into the streams where it mixed with direct runoff. The dissolved-solids content of the water flowing in the streams increased owing to biological activity and the solution of substances in the stream channels (item 6). The stream water underwent a marked further increase in dissolved-solids content (from about 20–40 ppm to hundreds and thousands of ppm) as the fresh water discharged into and mixed with the salty water in the estuarine reaches of the streams (item 7). Similarly, the dissolved-solids content of the ground water increased markedly (to thousands of ppm) as the fresh ground water mixed with salty ground water in the zone of diffusion (item 8).

PLATE 5A
CHANGES IN THE CHEMICAL QUALITY OF THE WATER ON LONG ISLAND, NEW YORK, UNDER NATURAL CONDITIONS

1. Air moving over the ocean picks up salty spray
2. Rain and snow pick up dust and gases from the atmosphere
3. Evaporation and transpiration of precipitation from the land surface and from the soil zone increase the dissolved-solids content of the water
4. Physical, chemical, and biological processes modify the dissolved-solids content of the water percolating through the zone of aeration
5. Flow through sedimentary deposits in the zone of saturation modifies the total dissolved-solids content of the ground water only slightly
6. Physical, chemical, and biological process modify the dissolved-solids content of streamflow
7. Fresh stream water and salty water mix in estuarine reaches
8. Fresh ground water and salty ground water mix in the zone of diffusion



Dissolved constituents in the water

Selected chemical analyses of six water samples from Long Island are shown on the accompanying plate (pl. 5B). These analyses are believed to be as nearly representative of the natural chemical quality of the fresh water as are any of the analyses that are presently available. Nevertheless, probably some, or perhaps all, of the waters represented by these samples were contaminated to some extent by the activities of man.

One of the most notable features of the analyses is the very low dissolved-solids content—ranging from 10 ppm to 47 ppm—of all the samples. This is especially significant because the commonly accepted upper limits for the dissolved-solids content of potable water supplies for human consumption is 500 ppm (U.S. Public Health Service, 1962, p. 7). In terms of all the constituents shown on the accompanying graphs, except iron, each sample is of excellent chemical quality for most uses. The iron content of the ground water from the Magothy aquifer (fig. 6), and from the Lloyd aquifer (fig. 7), and the iron content of the water in Cold Spring Brook (fig. 3), is considerably above the 0.3-ppm limit recommended for public-supply use. Water having an iron content in excess of 0.3 ppm (as does much of the ground water on Long Island) commonly stains plumbing fixtures, cooking utensils, and laundry unless it is specially treated before use.

A common manifestation of a low dissolved-solids content is the tendency for water to be corrosive to metals. This tendency, as well as the undesirably high dissolved-iron content of some of the natural ground waters of Long Island, commonly necessitates treatment of the waters before they are used.

As is to be expected from the previous discussion, precipitation (fig. 2) has the lowest dissolved-solids content—about 10 ppm. The ground-water samples (figs. 5, 6, and 7) have intermediate dissolved-solids concentrations of 15–36 ppm; and the surface-water samples (figs. 3 and 4) have the highest dissolved-solids concentrations (37 and 47 ppm). The data do not show the progressive increase that might be expected in dissolved-solids content as the water moves downward through the upper glacial aquifer into the Magothy aquifer and thence into the Lloyd aquifer. Two possible reasons for this apparent discrepancy are (1) the sampled water from the upper glacial aquifer might be slightly contaminated, and (2) the sampling points are not along a single ground-water flow path.

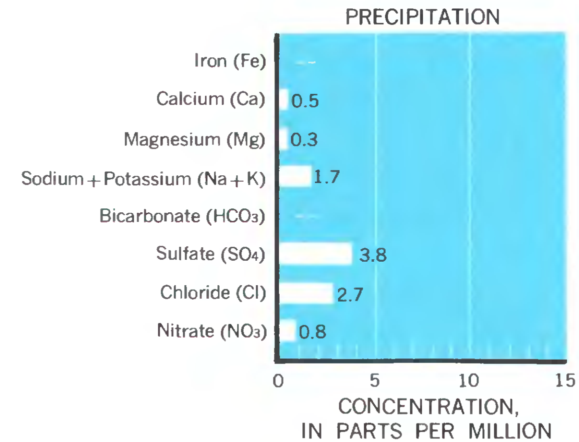


FIGURE 2. Quality of precipitation at the Brookhaven National Laboratory. Dissolved-solids content 10 ppm

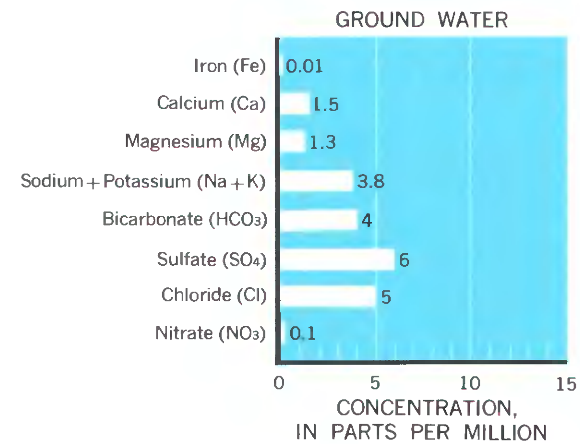


FIGURE 5. Quality of ground water in well S5518 (upper glacial aquifer). Dissolved-solids content 36 ppm

PLATE 5B
DISSOLVED CONSTITUENTS IN THE WATERS OF LONG ISLAND, NEW YORK

(Representing as nearly as possible waters uncontaminated by man's activities.)

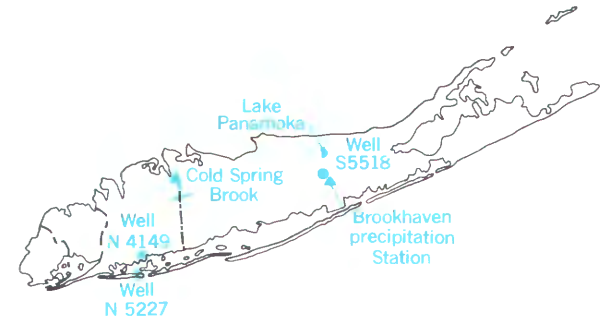


FIGURE 1. Location of sampling points.

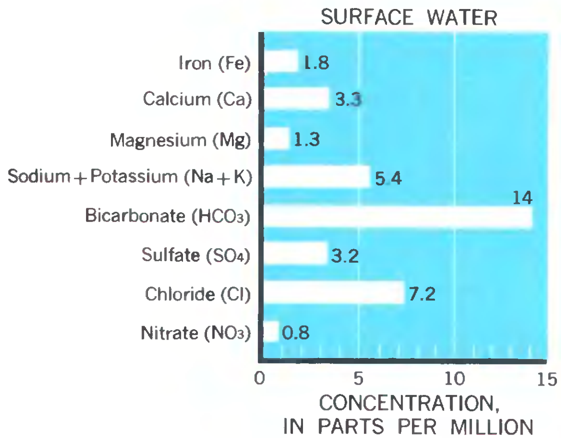


FIGURE 3. Quality of streamflow in Cold Spring Brook. Dissolved-solids content 37 ppm.

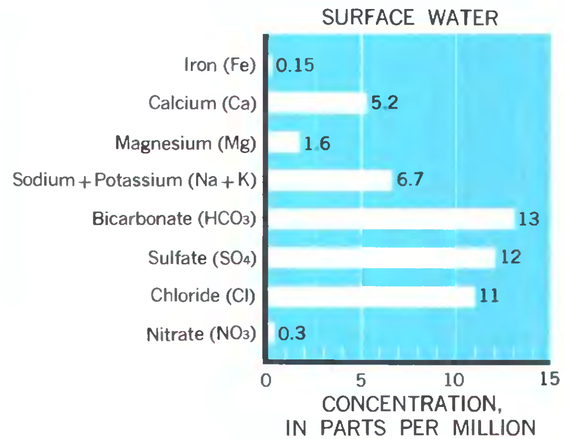


FIGURE 4. Quality of surface water in Lake Panamoka. Dissolved-solids content 47 ppm.

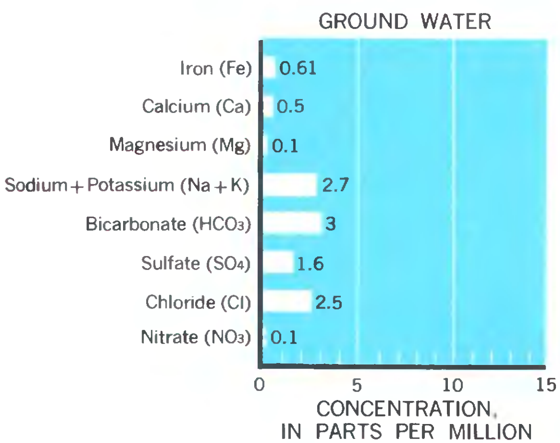


FIGURE 6. Quality of ground water in well N4149 (Magothy aquifer). Dissolved-solids content 15 ppm.

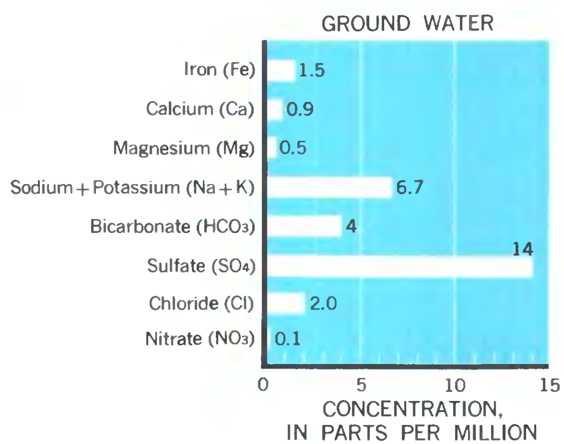


FIGURE 7. Quality of ground water in well N5227 (Lloyd aquifer). Dissolved-solids content 36 ppm.

A water-chemistry laboratory.

Relation between air temperature and water temperature

Temperature is one of the physical properties of the water of Long Island that has been studied intensively. Fundamental relations between air temperature and the temperature of surface water and shallow ground water at the gaging station on Sampawams Creek (fig. 1, pl. 5C) were studied and described by Pluhowski and Kantrowitz (1964, p. 64–73). For that study, air temperature and the temperature of the stream water were measured at the gaging station, and ground-water temperatures were measured in an adjacent shallow well, 7 feet deep.

The study showed that the temperatures of the air, stream water, and shallow ground water are related, with the temperature of the air fluctuating the most, and that of the ground water being most nearly constant. The range in average monthly air temperature in 1959–60 (fig. 2) was 43°F, and the ranges in average monthly surface-water and ground-water temperatures were 28°F and 16°F, respectively. The temperature of the ground water fluctuated least because of the insulating effect of the material in the zone of aeration. The temperature of the surface water was generally intermediate between that of the air and the ground water, even though most of the streamflow consists of seepage from the ground-water reservoir. The reason is that as soon as water discharges from the ground-water body into a stream (or lake), it becomes subject to the effects of the exchange of heat between the surface water and the air. When the water is cooler than the air, the water absorbs heat, and conversely when the water is warmer than the air, it loses heat.

The highest air temperatures occurred in the months of July and August and, similarly, the average temperature of the surface water also was highest during these months. Ground-water temperatures, however, were highest in September and October; the lag probably was caused by several factors including the slow rate of ground-water movement, and the insulating effect of the materials in the zone of aeration.

The average temperature of the ground water in the shallow well near Sampawams Creek was equal to the average annual air temperature—51°F. Under natural conditions, the average temperature of most of the ground water on Long Island ranged from about 50°F in the upper glacial aquifer to about 70°F in the Lloyd aquifer (DeLuca, Hoffman, and Lubke, 1965).

PLATE 5C

AVERAGE MONTHLY TEMPERATURE OF AIR, SURFACE WATER, AND SHALLOW GROUND WATER AT SAMPAWAMS CREEK, LONG ISLAND, NEW YORK, 1959–1960

(Modified from Pluhowski and Kantrowitz, 1964, fig. 20)

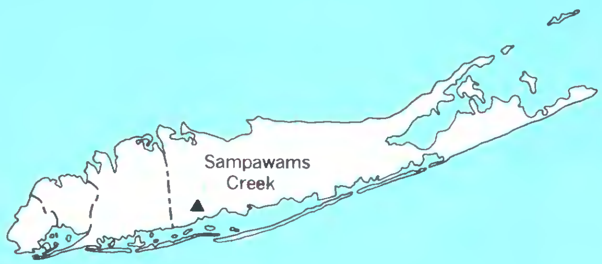


FIGURE 1. Location of Sampawams Creek.

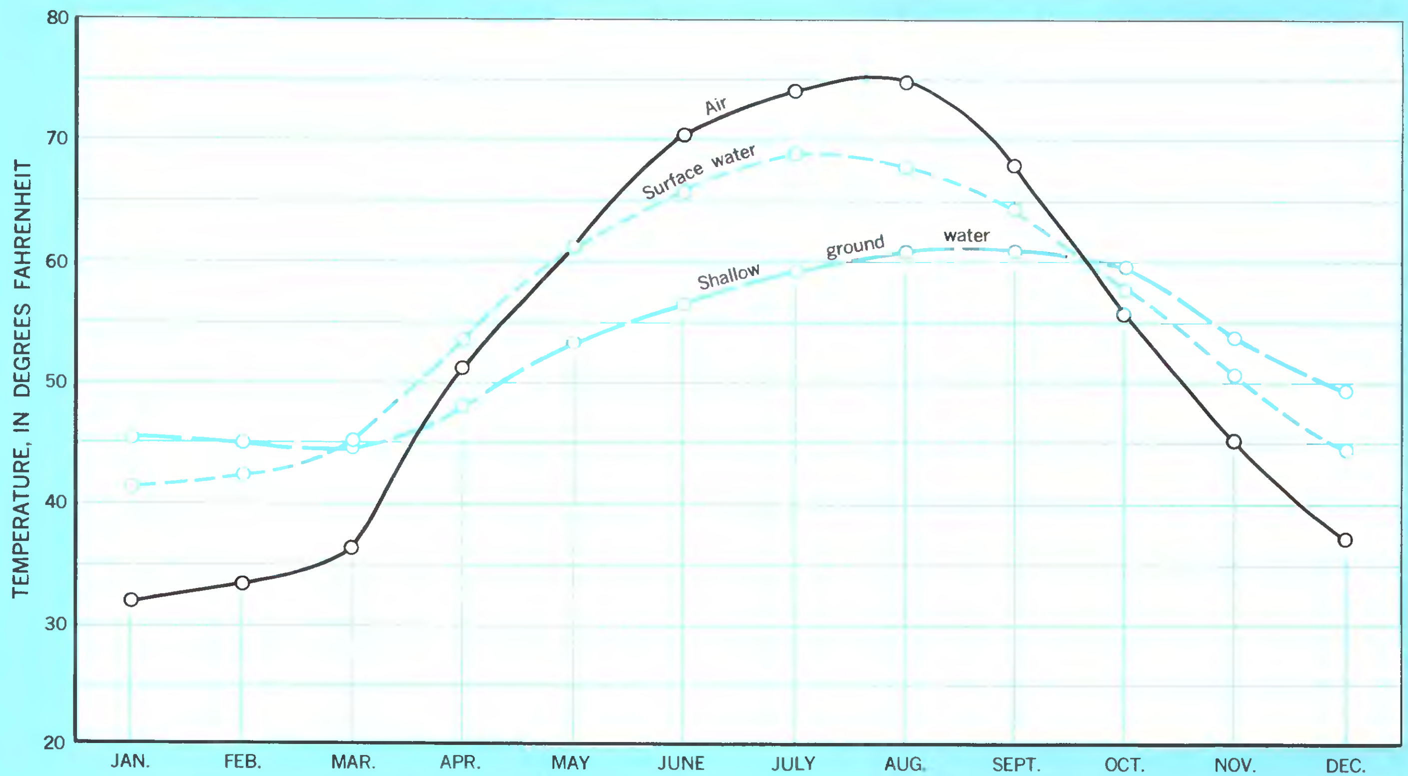


FIGURE 2. Air, ground-water, and surface-water temperature at Sampawams Creek.

Relation between ground-water temperature and depth

The seasonal variation in the temperature of the shallow ground water is related to the depth of the water-producing interval of the well. (See figs. 2 and 3, pl. 5D.) On Long Island, temperature variations range from about 2–3°F for wells whose screens (perforations) are at a depth of about 50 feet, to 15–20°F for wells screened at a depth of about 15 feet.

Under natural conditions, seasonal variations in ground-water temperatures largely reflect seasonal changes in air temperature, modified somewhat by the time lag described in the previous section. The decrease in the monthly range in ground-water temperatures with increasing depth (fig. 3) is mainly related to the insulating effect of the saturated and unsaturated materials above the screened interval—that is, the greater the thickness of these materials, the less the effect of changes in air temperature, and the smaller the resulting fluctuations in water temperature.

The relation between ground-water temperature and depth in two deep wells in the Brookhaven area was studied by deLaguna (1964, p. 31–32). As shown in figure 4, temperature in these wells, below a depth of about 400 feet, increases at a rate of about 1°F per hundred feet of depth. This increase is caused by a phenomenon known as the geothermal gradient—the normal increase in temperature with depth within the earth's crust. In other words, because the temperature of the earth's crust increases with depth, the temperature of the water in contact with the rock materials also increases with depth. The temperature of the water at the base of the upper glacial aquifer (at about 200 feet below land surface) is slightly cooler than the temperature of the water at the water table (fig. 4, pl. 5D). The reason for this relation is not apparent, and de Laguna (1964, p. 31) states, "It appears unlikely that density differences are responsible, and no explanation can be advanced. Many readings were taken, and the curve represents the actual temperature."

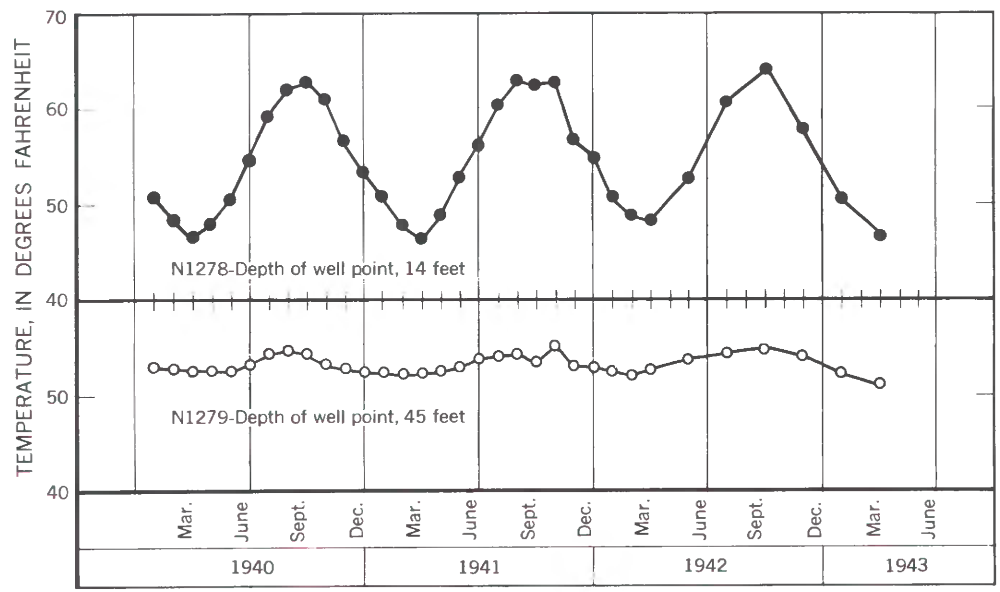


FIGURE 2. Monthly ground-water temperatures in two nearby wells in southern Nassau County. (Data obtained from DeLuca, Hoffman, and Lubke, 1965.)

PLATE 5D
RELATION BETWEEN
GROUND-WATER TEMPERATURE
AND DEPTH ON LONG ISLAND, NEW YORK

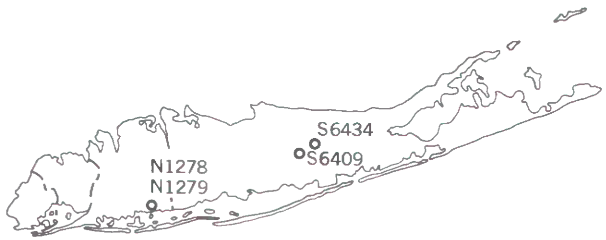


FIGURE 1. Location of selected wells in Nassau and Suffolk Counties.

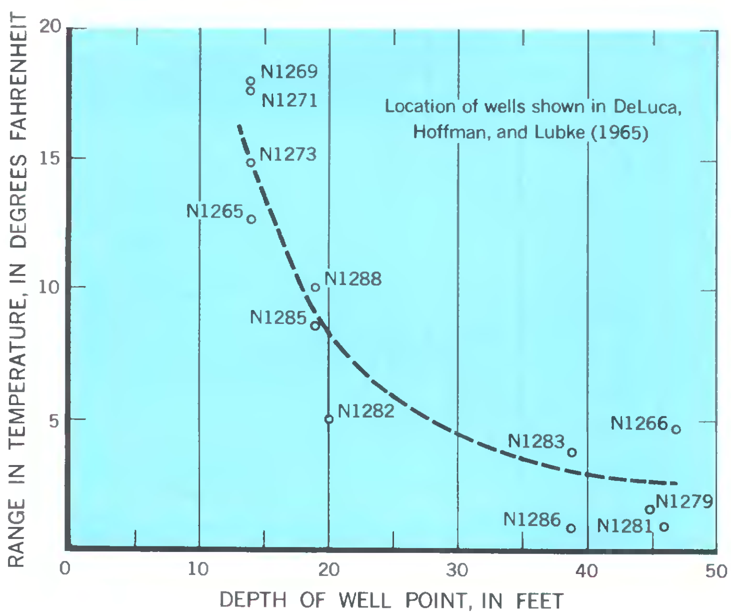


FIGURE 3. Range in ground-water temperatures measured monthly during 1940 in representative wells of different depths in southern Nassau County. (Data obtained from DeLuca, Hoffman, and Lubke, 1965.)

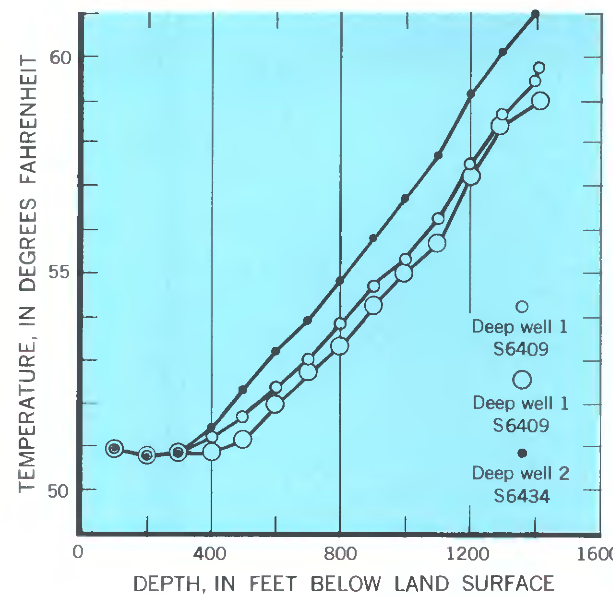


FIGURE 4. Ground-water temperatures at various depths in two deep wells at Brookhaven National Laboratory. (After de Laguna, 1964, fig. 15.)

6 SUMMARY OF RELATIONS BETWEEN THE COMPONENTS OF THE HYDROLOGIC SYSTEM

The hydrologic system under natural conditions

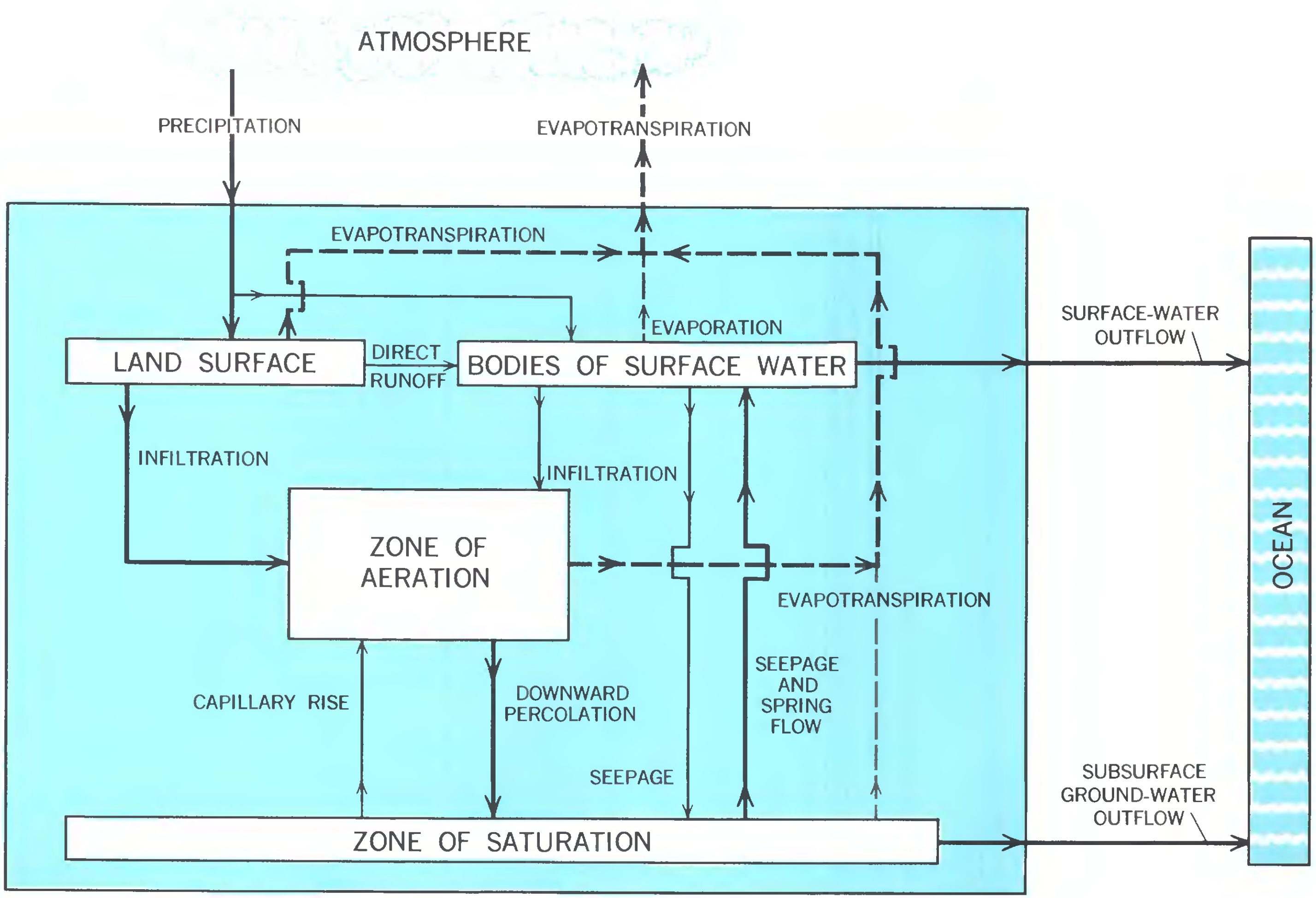
The major elements of the hydrologic system of Long Island are considered singly in the preceding chapters of this atlas. The general relations between these elements under natural conditions are summarized by means of the accompanying flow diagram (pl. 6A).

Under natural conditions, precipitation from the atmosphere was the only source of fresh water on and beneath the surface of Long Island. Most of the precipitation fell on the land surface, but a small amount fell directly on the streams and lakes. Slightly less than half the precipitation evaporated from the land surface or was transpired by plants from the soil zone soon after it fell, and most of the remainder, about 50 percent, percolated deeper into the zone of aeration and thence percolated downward into and recharged the zone of saturation. About 5 percent of the precipitation entered the streams as direct runoff. Most of the ground water was discharged by subsurface outflow to the sea and by seepage to streams. Small amounts of ground water, less than 10 percent, were discharged by evapotranspiration and by spring flow.

Minor, as well as major elements of the hydrologic system under natural conditions are shown on the accompanying flow diagram (pl. 6A). These elements are minor only in terms of the comparative quantities of water that are involved. Hydrologically and economically, the minor elements are highly significant. For example, direct runoff during intense storms locally can cause severe erosion. In addition, capillary rise from the zone of saturation to the zone of aeration locally may supply most, if not all, of the water to plants during periods of drought.

Prior to the development of water by man, the hydrologic system of Long Island was in a state of long-term dynamic equilibrium. That is, although inflow may have been larger or smaller than outflow for a short period of time, over periods of several decades or more the amount of water entering the system was balanced by, or was equal to, the amount of water discharging from the system.

PLATE 6A
FLOW DIAGRAM OF THE HYDROLOGIC SYSTEM, LONG ISLAND, NEW YORK, UNDER NATURAL CONDITIONS



EXPLANATION

Heavy lines represent major flow paths;
Thin lines represent minor flow paths;
Solid lines represent flow of liquid water;
Dashed lines represent flow of gaseous water.

Water-budget analysis

A water-budget analysis for any given area is a tally of all the items of inflow to, outflow from, and changes in the amount of storage within the area; it is a quantitative expression of the relations between the components of a hydrologic system. The items of a water budget are related by the equation:

Inflow = Outflow ± Change in Storage.

If the net change in storage is positive (denoting an increase), it is added to the right side of the equation; if it is negative (denoting a decrease in storage), it is subtracted. Inasmuch as the hydrologic system of Long Island was in long-term dynamic equilibrium under natural conditions (inflow = outflow), the average net change in storage was zero.

A water budget for the 26-year index period, water years 1940–65, for the water-budget area on Long Island is given on plate 6B. Although the amount of fresh ground water in storage locally has decreased markedly, the average decrease in storage is small. Moreover, in comparison to the total inflow and outflow the decrease in storage is insignificant, and Therefore, is disregarded in the water budget analysis.

As mentioned earlier in this atlas (p. 46), sufficient data are not available to readily estimate subsurface ground-water outflow from the water-budget area. Therefore, the value for this element in the overall water budget (470 mgd) was obtained by calculating the quantity needed to fulfill the requirement that total inflow is equal to total outflow under long-term equilibrium conditions. The general magnitude of this estimate of subsurface outflow was confirmed by calculations of outflow using preliminary data on permeability and seaward hydraulic gradients.

The estimate of subsurface ground-water outflow probably is subject to the greatest error of any of the elements in the foregoing budget, because it necessarily includes possible errors in the estimates of each of the other components of the water budget. Also, locally, moderately large quantities of water have been removed from storage in the ground-water reservoir, whereas the estimate of 470 mgd is based on the assumption that the average change in the amount of ground water in storage for the entire water-budget area was negligible during the index period.

If the additional simplifying assumption is made that, during the index period (water years 1940–65), changes in natural ground-water recharge and discharge were roughly compensated for by artificial recharge and discharge, an approximate ground-water budget can be developed as follows:

GROUND-WATER-BUDGET ANALYSIS FOR THE WATER-BUDGET AREA ON LONG ISLAND, N. Y., WATER YEARS 1940–65 [1]

Inflow	MGD
7 Ground-water recharge (p. 44)	820
Outflow	
8 Ground-water discharge to streams (p. 38)	320
9 Subsurface outflow of ground water (p. 58)	470
10 Evapotranspiration of ground water (p. 46)	15
11 Spring flow (p. 46)	15
Subtotal (items 8–11)	820

Change in ground-water storage---Negligible

MGD = Million gallons per day

[1] The page numbers following each item, are the pages in the atlas on which the items are discussed.

OVERALL WATER-BUDGET ANALYSIS[1]

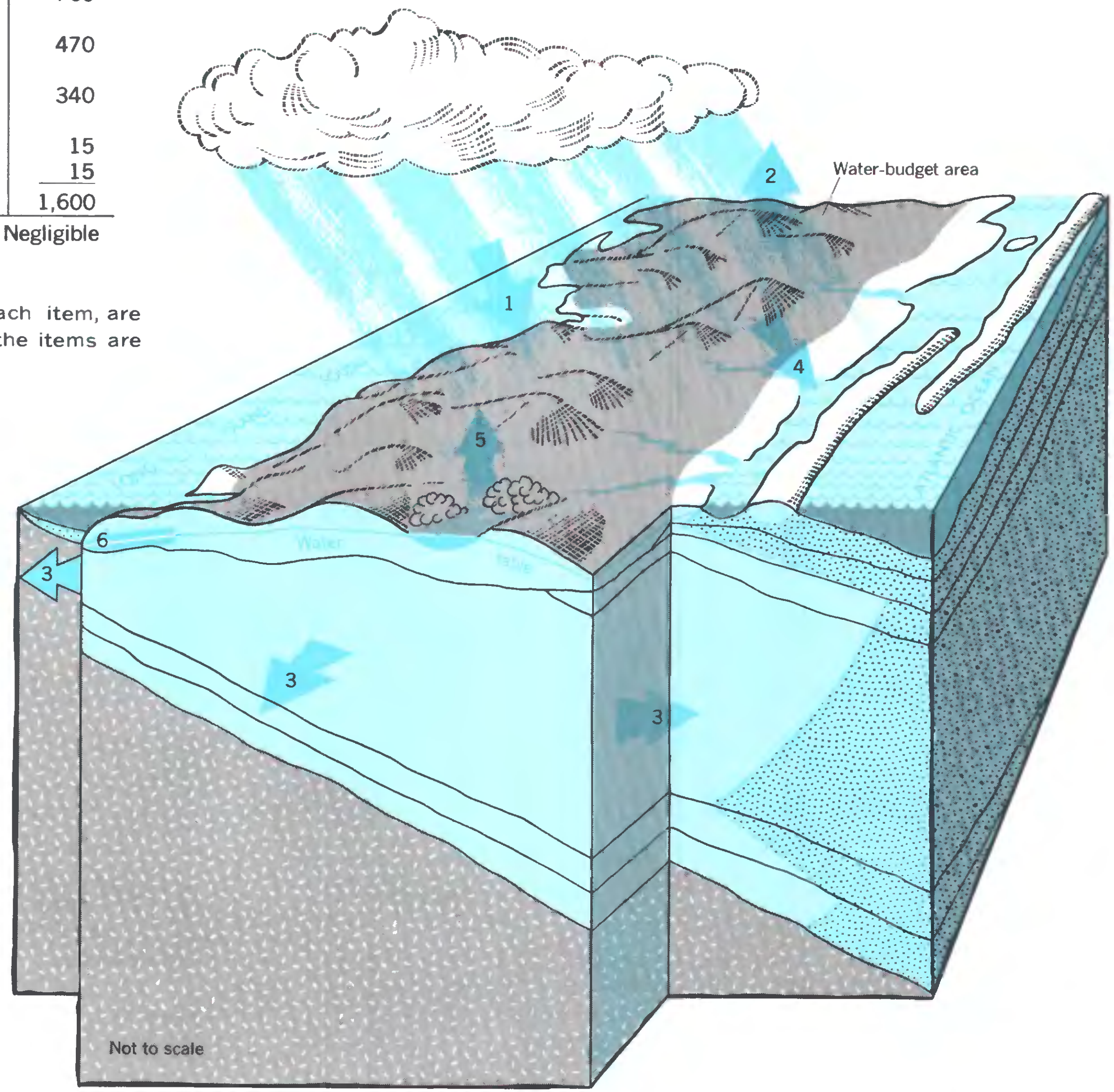
Inflow	MGD
1 Precipitation (p. 30)	1,600
Outflow	
2 Evapotranspiration of precipitation (p. 36)	760
3 Subsurface outflow of ground water (p. 58)	470
4 Streamflow discharging to salt water (p. 38)	340
5 Evapotranspiration of ground water (p. 46)	15
6 Spring flow (p. 46)	15
Subtotal (items 2–6)	1,600
Change in storage	Negligible

MGD = Million gallons per day

[1]The page numbers following each item, are the pages in the atlas on which the items are discussed.

PLATE 6B
OVERALL WATER-BUDGET ANALYSIS FOR WATER YEARS 1940–1965

(Analysis is for the 760 square miles of Long Island designated the "water-budget area".)



Relation between estimated average monthly ground-water recharge and ground-water levels

The relation between ground-water recharge and ground-water levels has long been of considerable interest to those concerned with the hydrology of Long Island. A comparison of figures 1 and 2 on the accompanying plate (pl. 6C) indicates that there is little or no direct correlation between the estimated average monthly ground-water recharge (computed in the manner described on p. 44) and the average monthly ground-water levels in 14 selected water-table wells on Long Island. On the other hand, there seems to be an excellent correlation between the average monthly ground-water levels and the cumulative departure from estimated average monthly recharge (figs. 2 and 3, pl. 6C).

This correlation can be explained best within the context of the water-budget concept (the law of hydraulic continuity). Changes in ground-water levels represent changes in the amount of ground water in storage. Therefore, ground-water levels respond to differences between recharge and discharge, and not necessarily to the absolute amount of either one of these elements alone. For example, if recharge in a given month is below normal or if it is less than that in the preceding month, ground-water levels may nevertheless rise, provided only that the amount of ground-water discharge in that month is less than the recharge.

On the average, the seaward slopes of the water table and the piezometric surfaces (the hydraulic gradients) vary only slightly from month to month on Long Island. Accordingly, subsurface ground-water outflow, which constitutes more than 50 percent of the total natural ground-water discharge from the water-budget area, tends to remain nearly constant from month to month. Moreover, seasonal variations in ground-water discharge to streams are at least partly compensated for by changes in the rate of evapotranspiration of ground water. For example, in the winter when ground-water seepage to streams begins to increase, ground-water evapotranspiration decreases. Therefore, the month-to-month variations in ground-water discharge tend to be less than the month-to-month variations in ground-water recharge. In other words, ground-water discharge is more nearly constant throughout the year than is ground-water recharge. It follows, therefore, that ground-water levels will tend to rise in those months when recharge is above average and will tend to decline when recharge is below average (fig. 2, pl. 6C).

PLATE 6C
RELATION BETWEEN ESTIMATED AVERAGE MONTHLY GROUND-WATER RECHARGE AND GROUND-WATER LEVELS ON LONG ISLAND, NEW YORK, WATER YEARS 1940–1965

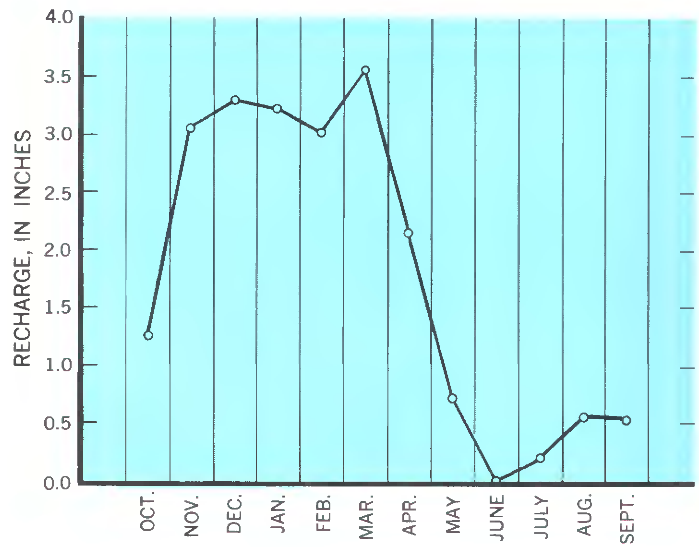


FIGURE 1. Estimated average monthly recharge.

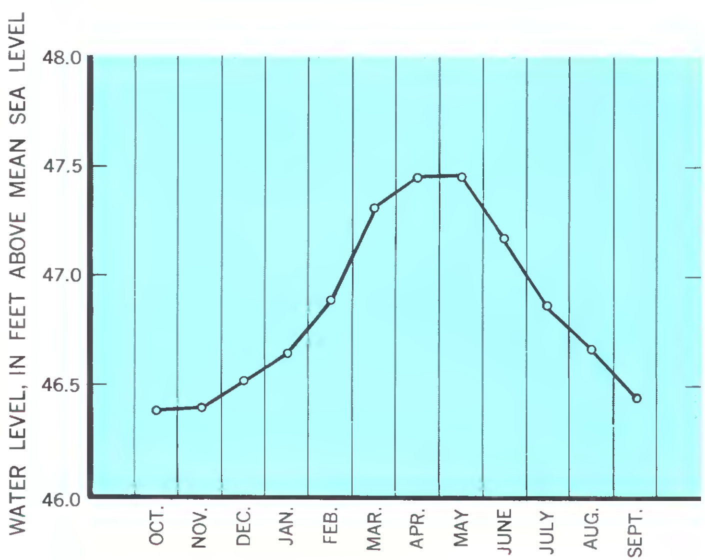


FIGURE 2. Composite average monthly water level in 14 water-table wells in Nassau and Suffolk Counties.

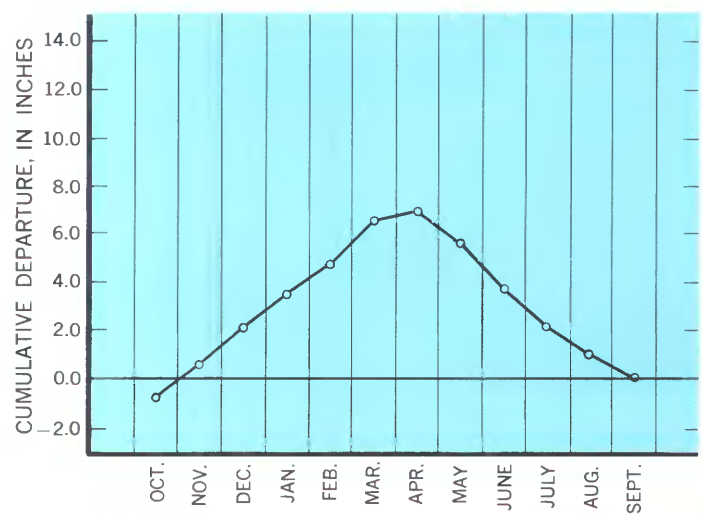


FIGURE 3. Cumulative departure from estimated average monthly recharge.

Relation between estimated annual recharge, ground-water levels, and streamflow

On an annual basis, the correlation between average ground-water recharge and average ground-water levels (pl. 6D) is somewhat better and more obvious than similar correlations on a monthly basis (figs. 1 and 2, pl. 6C). Nevertheless, a comparison of these two elements of the hydrologic system of Long Island, on whatever time base, generally does not indicate a good direct relationship. On the other hand, the correlation is generally good (with some discrepancies) between annual average ground-water levels and the flow of the 19 major streams on Long Island.

The amount of ground water that discharges into the streams of Long Island is directly proportional to the water-table gradient in the vicinity of the streams. In other words, if hydraulic gradients in the shallow glacial deposits decrease by 50 percent, the amount of ground water discharging into the streams decreases by about 50 percent. Inasmuch as more than 95 percent of Long Island's streamflow, on the average, is derived from the ground-water reservoir, it follows that most changes in streamflow are related to changes in water-table gradients. Moreover, because water-table gradients in the vicinity of Long Island's streams are directly related to the altitude of the water table near the stream, streamflow decreases when the water table declines, and increases when the water table rises.

The most dramatic decrease in streamflow ever recorded occurred in water years 1962–65 as a result of the severe drought. The annual average flow of the 19 major streams on Long Island decreased by more than 150 cfs. During the same period, the cumulative departure from normal precipitation was about 28 inches (p. 34), and the decline in the average of the water levels in 14 selected wells on Long Island was almost 5 feet (fig. 2, pl. 6D).

PLATE 6D
RELATION BETWEEN ESTIMATED ANNUAL RECHARGE, GROUND-WATER LEVELS, AND STREAMFLOW ON LONG ISLAND, NEW YORK, WATER YEARS 1940–1965

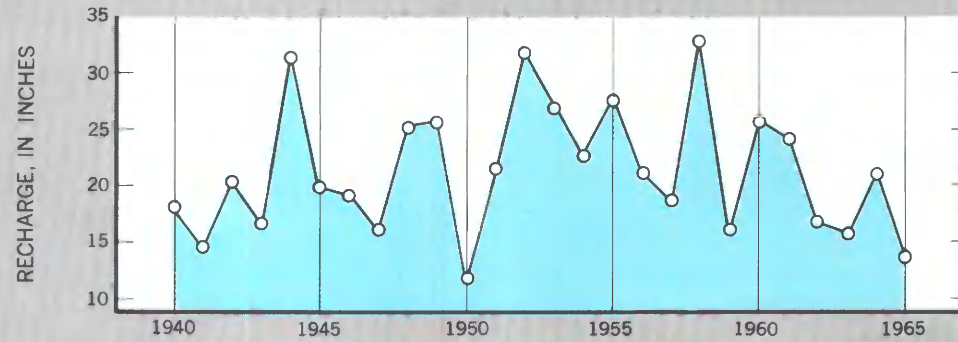


FIGURE 1. Estimated annual recharge.

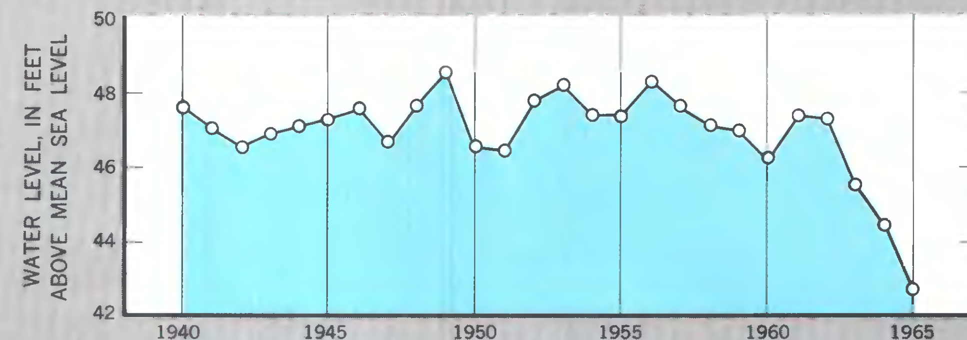


FIGURE 2. Annual average water levels in 14 wells in Nassau and Suffolk Counties.

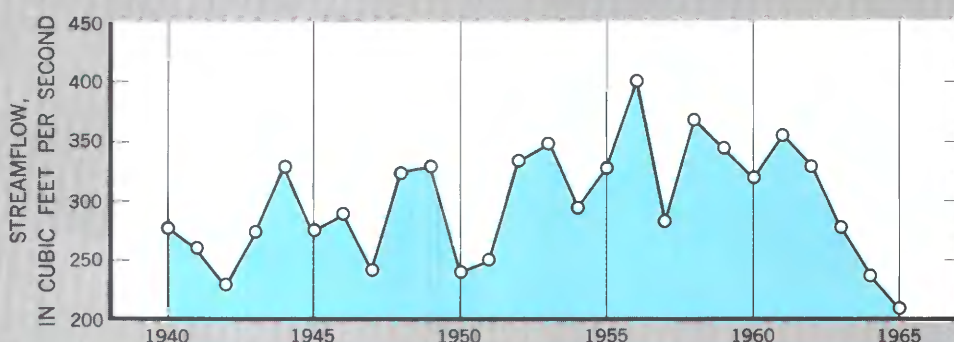


FIGURE 3. Annual average flow of 19 streams in Nassau and Suffolk Counties.

7 HOW MAN HAS CHANGED THE NATURAL HYDROLOGIC SYSTEM

History of development

Ground-water development on Long Island has progressed through three major stages. In the first stage of development (fig. 1, pl. 7A), which began with the arrival of the first European settlers, almost every house had a shallow dug well from which water was withdrawn from the upper glacial aquifer. Most of the domestic waste water was returned to the shallow upper glacial aquifer through individually owned cesspools. As the population increased, many individually owned wells were abandoned, and public-supply wells were installed in the upper glacial aquifer; however, the disposal of waste water through individually owned cesspools continued. Although the quality of the water gradually deteriorated as a result of these practices, the amount of water permanently removed (the "net withdrawal") from the ground-water system was negligible, and in overall aspect the system remained in quantitative balance.

Pollution of the shallow part of the ground-water reservoir by water from cesspools eventually forced the abandonment of many wells tapping the upper glacial aquifer. These wells were replaced by deeper public-supply wells mainly tapping the Magothy and Jameco aquifers (fig. 2, pl. 7A). Most of the domestic and industrial sewage, however, was still returned to the upper glacial aquifer through cesspools and septic tanks. Accordingly, the net withdrawals from the entire ground-water reservoir remained negligible; however, a local hydrologic imbalance resulted in the Magothy aquifer and the Jameco aquifer because the rate of downward flow to the deeper artesian aquifers from the overlying glacial aquifer was less than the rate of pumping from the artesian aquifers. The imbalances resulted in local decreases in the amount of fresh ground water in storage in the Magothy and Jameco aquifers and a concurrent landward movement of salty ground water.

The third major stage of ground-water development (fig. 3, pl. 7A) was characterized mainly by the introduction of large-scale sewering systems—first in Kings and Queens Counties and then in the western half of Nassau County. After the sewers were installed, most of the once-used water that previously had been returned to the ground-water reservoir through cesspools and septic tanks was thereafter discharged to the sea. Prior to the third stage of development, the net draft on the ground-water system was negligible. However, after the installation of extensive sewers, practically all the ground water diverted to the sewers represented a permanent loss of water from the system. The resulting disruption of the hydrologic balance caused large-scale salt-water encroachment, first in Kings County, then in Queens County, and most recently in the southwestern part of Nassau County. (See p. 82).

Drilling a well on Long Island

PLATE 7A
HISTORY OF WATER DEVELOPMENT
ON LONG ISLAND, NEW YORK
IN 1966

(After Heath, Foxworthy, and Cohen, 1966, figs. 5–7)

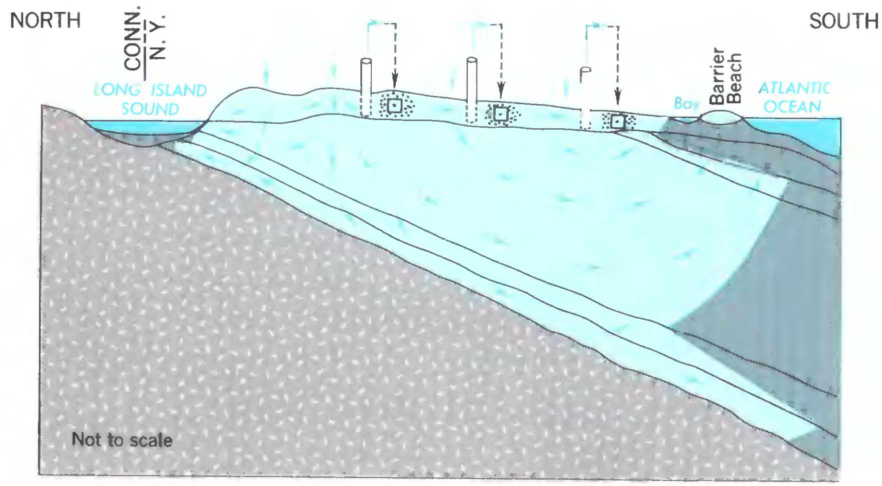


FIGURE 1. First stage of development

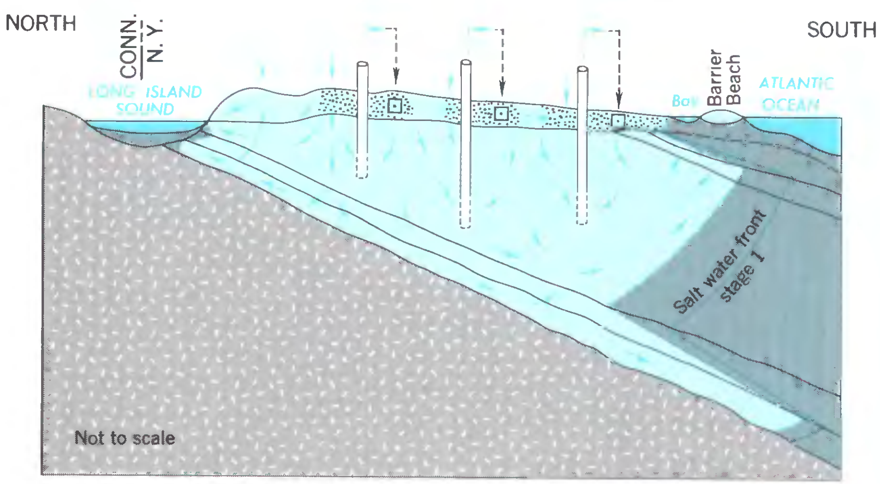


FIGURE 2. Second stage of development

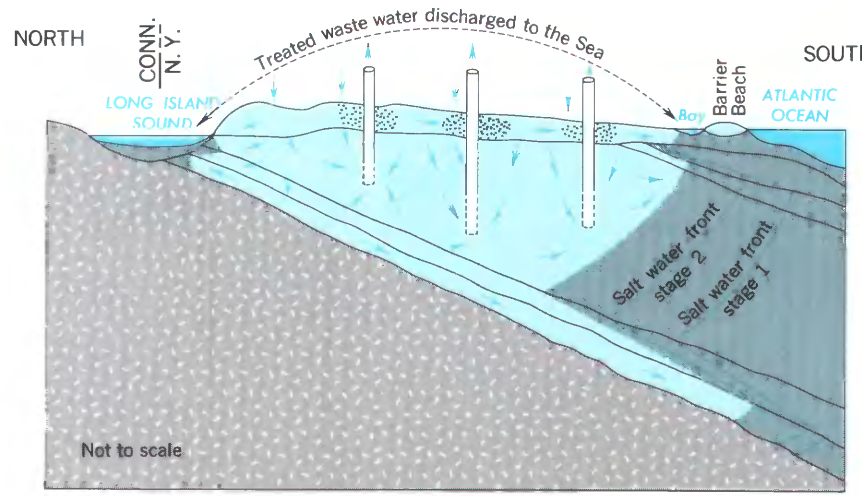
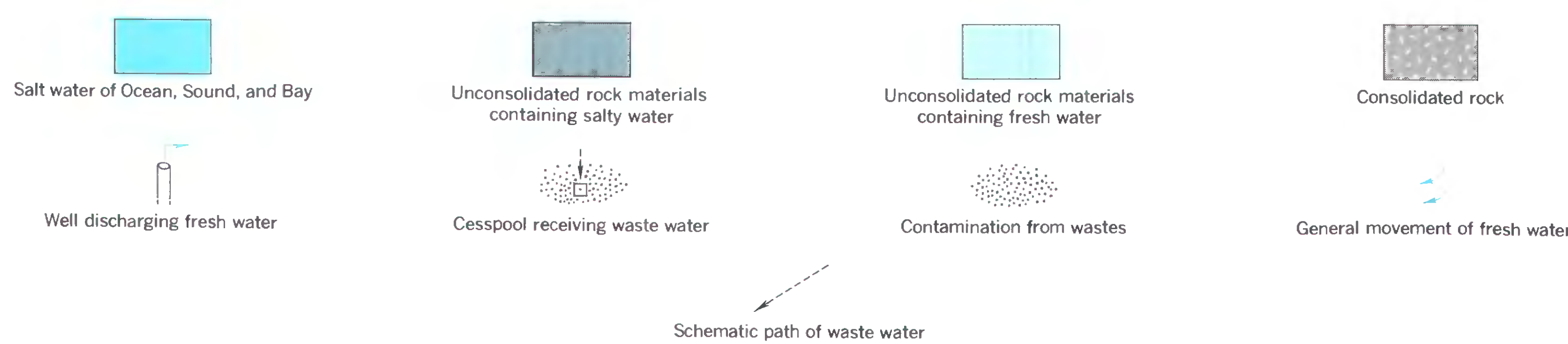


FIGURE 3. Third stage of development

EXPLANATION



Present status of development

The three major stages of development, as well as transitional stages, can presently be observed in different subareas of Long Island (pl. 7B). Subarea A is largely rural and has the lowest population density on the island. In general, most of the subarea is in the first major stage of development. That is, for the most part, individually owned wells tapping the upper glacial aquifer supply water to single-family dwellings. Most of the waste water is discharged to the same shallow deposits through privately owned cesspools and septic tanks. Although these practices are causing the gradual contamination of the shallow ground-water reservoir, and although increases in pumpage locally (near the shores) cause problems involving salt-water encroachment, the draft on the system in most of subarea A is practically negligible and the system still is in a state of virtual quantitative equilibrium.

Subarea B is mainly in a stage of development intermediate between the first and second stages of development. Farms in the area are rapidly being replaced by housing developments, and the new homes are being supplied with water from large-capacity public-supply wells tapping the upper glacial aquifer. Most of the new homes have individual cesspools to dispose of domestic waste water. The ground-water system in this subarea also is still in a virtual state of dynamic equilibrium, although the quality of the shallow ground water undoubtedly is being degraded in the vicinity of the cesspools and septic tanks.

Because it is closer to New York City, subarea C experienced intensive suburban development earlier than subarea B. In addition, most of the subarea is not sewered. As a result, fairly large parts of the shallow upper glacial aquifer have become polluted with cesspool effluent. This, in turn, has forced the abandonment of many of the shallow wells, and most of the water supply for the subarea presently is obtained from deep wells tapping the Magothy aquifer. The subarea, therefore, is in the second major stage of ground-water development. Locally, the ground-water system in the Magothy aquifer is quantitatively out of balance. Substantial widespread salt-water encroachment has not yet been noted, but is to be expected if the present trend in development continues.

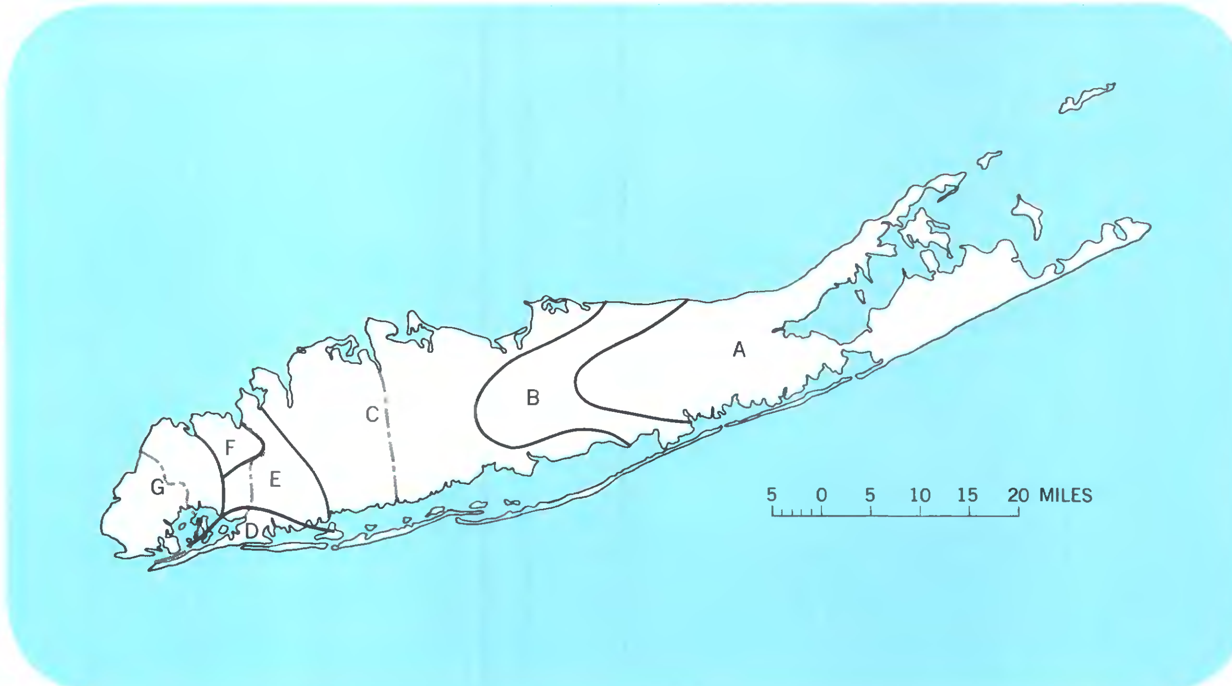
Subarea D is in the third major stage of development. Public-supply water is derived mainly from large-capacity wells tapping the Magothy and Jameco aquifers, and most of the sewage water is discharged to the sea by way of large-capacity sewage-plant facilities. The ground-water system in the Magothy and Jameco aquifers is no longer in quantitative equilibrium, and salty water from the ocean is actively invading these aquifers.

Subarea E also is in the third major stage of development. It differs from subarea D mainly because the salty water has not yet invaded the aquifers in this subarea. However, if the trend continues, subarea D will expand at the expense of subarea E, and the aquifers in subarea E also will be contaminated with salty water.

PLATE 7B
STATUS OF WATER DEVELOPMENT ON LONG ISLAND, NEW YORK, IN 1966
(After Heath, Foxworthy, and Cohen, 1966, fig. 8.)

Almost all the public-supply water for subarea F, which is in northeastern Queens County, is derived from surface-water supplies imported from upstate New York. The subarea is sewered; however, because ground-water development is negligible, the ground-water system is still in balance.

All of subarea G, the most highly urbanized part of Long Island, is sewered. Presently, the subarea receives more than 85 percent of its public-supply water from the upstate surface-water reservoirs of the New York City municipal-supply system. As is described in a subsequent part of the report (p. 82), large parts of the ground-water reservoir in the subarea have been contaminated with salty water because of substantial overdevelopment. Since the mid 1940's, when pumpage in the subarea had to be drastically reduced because of the salt-water contamination, ground-water levels in the subarea have recovered markedly.



EXPLANATION

Subarea	Characteristics
A	Hydrologic system mainly is in a state of virtual quantitative equilibrium.
B	Transitional in development between subareas A and C.
C	Hydrologic system is locally out of balance; local salt-water intrusion.
D	Hydrologic system is out of balance; widespread salt-water intrusion.
E	Hydrologic system is out of balance; may be subject to salt-water intrusion in the future.
F	Ground-water development is negligible, and the hydrologic system is in balance
G	Large parts of the subarea are contaminated with salty ground water due to former intensive ground-water development and related salt-water intrusion.

Changes in streamflow caused by urbanization

Locally, urbanization has markedly changed the streamflow regimen on Long Island. In Kings County and in the highly urbanized parts of Queens County, most of the streams have been rerouted, and many of them have been filled in and covered with impermeable streets and highways. Most of the direct runoff in these areas presently is routed to the sea through sewers.

The effect of urbanization on the flow of East Meadow Brook was first studied by Sawyer (1963). Urbanization of the drainage area, notably the construction of large, single-family, housing developments has increased rapidly since 1952. Storm drains were built to carry runoff to East Meadow Brook, and as a result, some of the precipitation that formerly would have infiltrated into the ground was diverted into the brook. The resulting increase since 1952 in the proportion of direct runoff for various amounts of annual precipitation is clearly shown in figure 2 of the accompanying plate (pl. 7C).

G. E. Seaburn (1966, written communication) studied the effects of urbanization in the East Meadow Brook area on the magnitude and the distribution of runoff resulting from individual storms (fig. 3, pl. 7C). For two storms that were closely comparable in the magnitude and duration of their precipitation, the peak flow of the stream occurred sooner, was more sharply defined, and was of greater magnitude in 1958 than in 1940. It is presumed that these changes in runoff characteristics were largely related to an increase during the period in the number of storm drains leading to the stream and in the impermeable surface area draining into the stream. These features resulted in a larger percentage of direct runoff and a more rapid arrival of the runoff at the stream.

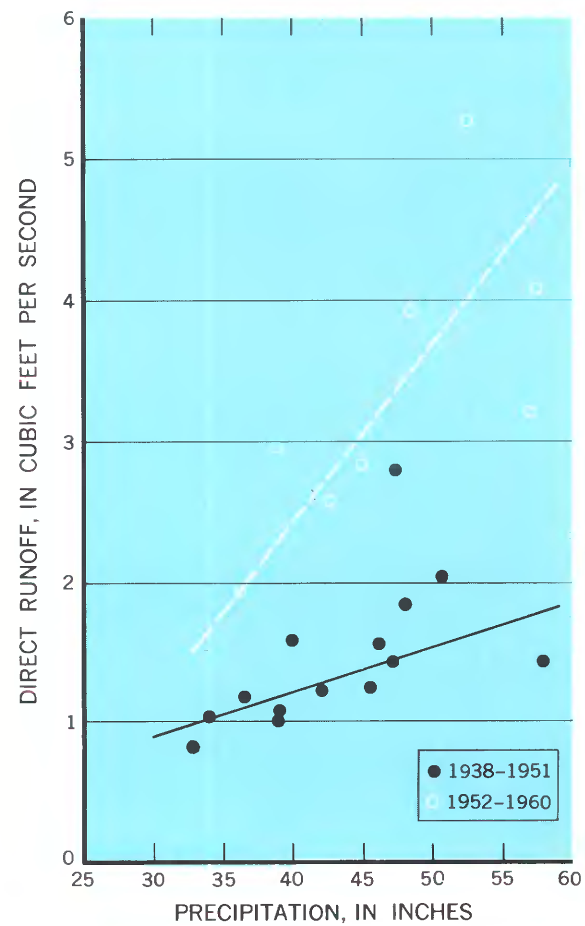


FIGURE 2. Relation between annual precipitation at Mineola and annual direct runoff into East Meadow Brook, 1938–1960. (Based on data from Sawyer, 1963.)

PLATE 7C
CHANGES IN STREAMFLOW CAUSED BY URBANIZATION
ON LONG ISLAND, NEW YORK

FIGURE 1. Location of East Meadow Brook and the Mineola precipitation station.

Urban development disturbing a natural stream channel.

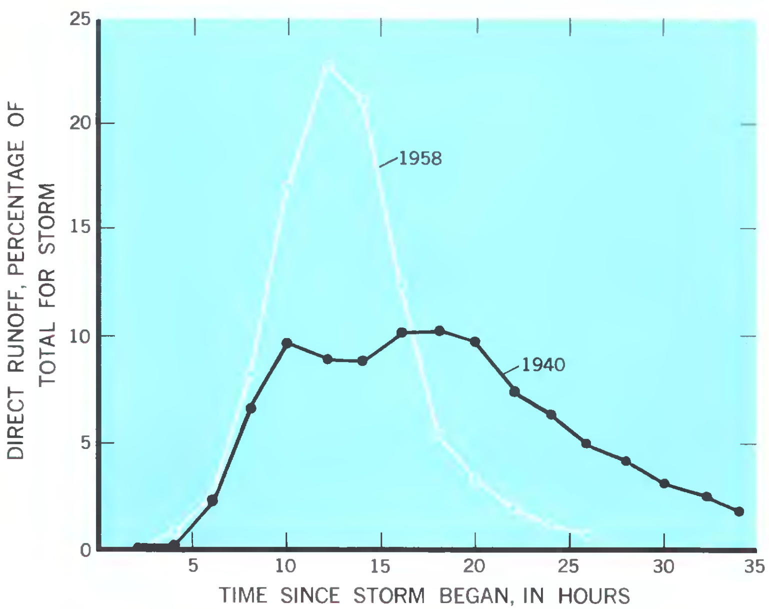


FIGURE 3. Time distribution of direct runoff in East Meadow Brook reflecting storms on April 8, 1940 and April 27–28, 1958. (After G. E. Seaburn, 1966, written communication.)

Ground-water pumpage

Substantial quantities of ground water have been and are being withdrawn from the ground-water reservoir of Long Island. The total amount of water withdrawn from wells is termed the gross pumpage.

In Kings County, gross pumpage decreased from an average of about 60 mgd in 1940 to about 25 mgd in 1955 (fig. 1, pl. 7D). In the past 10 years, the average remained virtually constant at about 24 mgd. The decrease in gross pumpage in Kings County is related mainly to (a) the abandonment of many wells owing to salt-water contamination of the ground-water reservoir in the area, (b) closing of nearly all of the numerous ice plants in the county, and (c) the concurrent increase in the use of water from the New York City municipal-supply system that is derived from upstate New York.

In Queens County also, an increasing proportion of the public water supply has been derived from upstate surface-water sources; however, ground-water pumpage in the county has increased progressively in the past 26 years, from an average of about 55 mgd in 1940 to about 78 mgd in 1965 (fig. 2, pl. 7D). For many years, two privately owned companies have been providing part of the public water-supply requirements in Queens County from wells in the county. Accordingly, as the demand for water within the area serviced by the private companies has increased, new wells have been drilled and ground-water withdrawals have increased.

In Nassau and Suffolk Counties, inasmuch as ground water has been practically the only source of public-supply water, gross pumpage has increased as the population increased. In Nassau County, it increased from about 75 mgd in 1940 to nearly 210 mgd in 1965 (fig. 3, pl. 7D). Similarly, gross pumpage in Suffolk County increased from about 30 mgd in 1940 to almost 120 mgd in 1965 (fig. 4, pl. 7D). Total ground-water pumpage on all of Long Island increased from 220 mgd in 1940 to about 430 mgd in 1965 (fig. 5, pl. 7D)

Not all the gross pumpage represents a loss of water from Long Island's hydrologic system. As is discussed subsequently in this atlas, most of the gross pumpage is returned to the ground-water reservoir following its use. The proportion that actually is lost (termed net pumpage or net withdrawal) depends upon the type of water use and the method of waste-water disposal. In general, industrial and commercial uses of ground water on Long Island involve large gross pumpage but do not result in large permanent losses of water from the system. Conversely, agricultural uses (mostly for irrigation) involve relatively small average gross pumpage, but a large percentage of the water used for agriculture is permanently lost from the system. Public-supply uses require the greatest gross withdrawal, and the losses therefrom range from small to large, depending on the type of waste-water disposal.

Tabulations of pumpage and water use (obtained mainly from the New York State Water Resources Commission) indicate that the average per capita use of ground water in Nassau and Suffolk Counties decreased from about 180 gallons per day in 1940 to 140 gallons per day in 1965. This decrease mainly reflects the very marked suburban expansion and the resulting relative increase in the amount of water used for domestic purposes as compared to the amount of water used for industrial purposes. The per capita use of ground water also has decreased in Kings and Queens Counties, but this has been largely the result of the increased use of water imported from upstate New York.

PLATE 7D

GROSS GROUND-WATER PUMPAGE ON LONG ISLAND, NEW YORK, 1940-1965

(Based mainly on unpublished data from the New York State Water Resources Commission.)

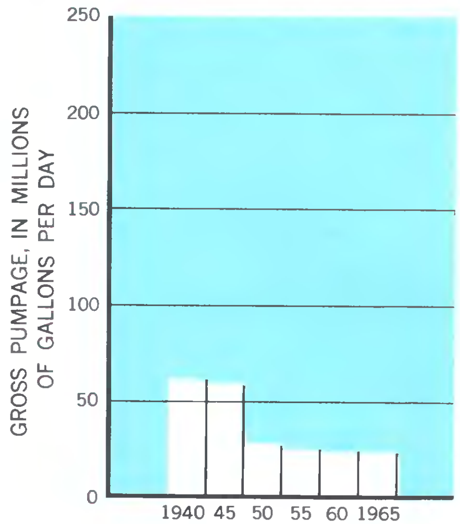


FIGURE 1. Gross pumpage in Kings County.

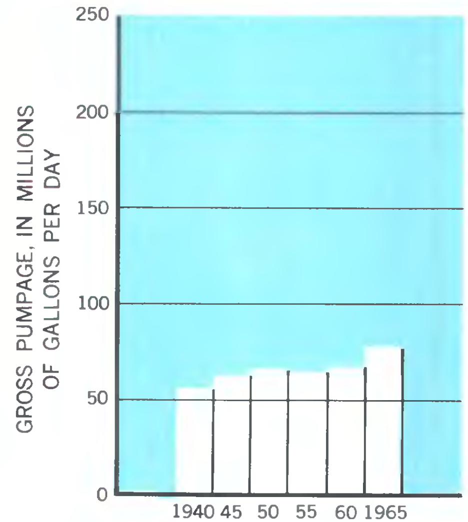


FIGURE 2. Gross pumpage in Queens County.

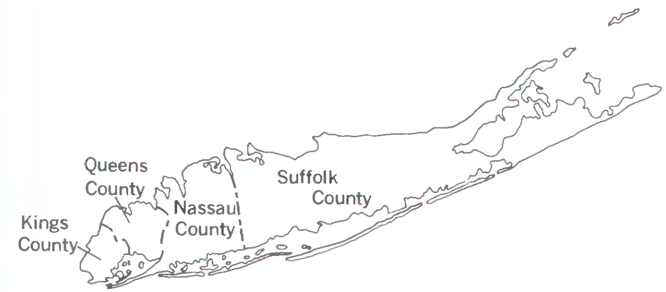


FIGURE 6. Location of counties.

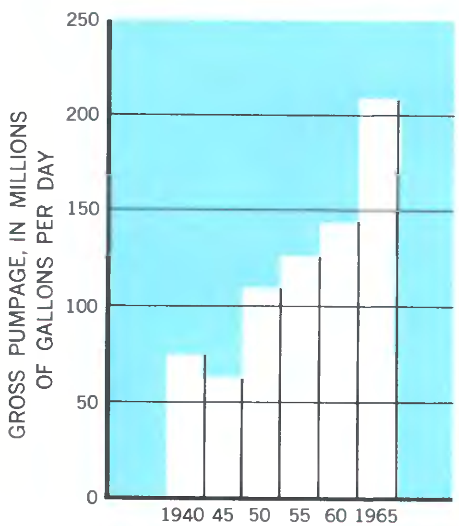


FIGURE 3. Gross pumpage in Nassau County.

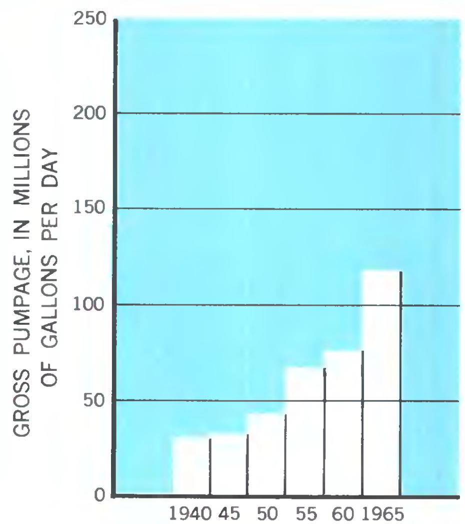


FIGURE 4. Gross pumpage in Suffolk County.

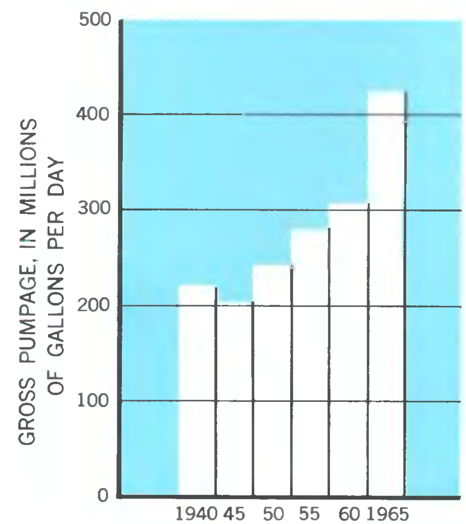


FIGURE 5. Total gross pumpage in Kings, Queens, Nassau, and Suffolk Counties.

Discharge of treated sewage-plant effluent to the sea

Large quantities of treated sewage-plant effluent were discharged into the sea from Long Island during the index period, water years 1940–65; however, data are not readily available for the amounts discharged from Kings and Queens Counties during the first 10 years of this period. Therefore, only data for calendar years 1950–65 are shown on the accompanying plate.

The annual average discharge of treated sewage-plant effluent from Kings County (fig. 1, pl. 7E) increased from a low of about 100 mgd in 1950 to a high of almost 250 mgd in 1963; the range and progressive increase were roughly similar in Queens County (fig. 2, pl. 7E). The increase in the amount of treated sewage-plant effluent that was discharged to the sea from Kings and Queens Counties was caused almost entirely by an increase in sewage-treatment facilities rather than by an increase in the use of water in these counties. In other words, the amount of untreated sewage that was discharged into the sea has decreased in Kings and Queens Counties in the past 15 years.

In 1965 the total discharge of sewage (treated and untreated) to the sea from Kings and Queens Counties averaged about 500–600 mgd. Most of this sewage water was derived from the New York City upstate municipal-supply system, but some of it was direct runoff that flowed into combined sanitary and storm-runoff sewers, and some of it (less than 100 mgd) was withdrawn from the ground-water reservoir of Long Island.

Virtually all the treated sewage that was discharged into the sea from Nassau and Suffolk Counties was derived from the ground-water reservoir. The increase in the amount that was discharged from Nassau County from 1950 to 1965 (fig. 3, pl. 7E) partly reflected increased pumpage during that period, but mainly was the result of the completion of the Nassau County Sewer District No. 2 secondary-treatment plant (shown as number 13 on the accompanying plate, and locally referred to as the Bay Park sewage-treatment plant). In 1965, an average of about 50 mgd was discharged into the sea from the Bay Park plant.

The low and nearly constant rate of discharge to the sea of treated sewage from Suffolk County mainly reflects the fact that most of the sewage in that county is disposed of through individually owned cesspools and septic tanks, and the fact that the capacity of the existing sewage-treatment facilities in the county has not increased appreciably in the past 15 years.

Sewage treatment plant on the north shore of Long Isla

PLATE 7E
DISCHARGE OF
TREATED SEWAGE-PLANT EFFLUENT TO THE SEA
FROM LONG ISLAND, NEW YORK, 1950-1965

(Data from annual reports of the New York, New Jersey, and Connecticut Interstate Sanitation Commission.)

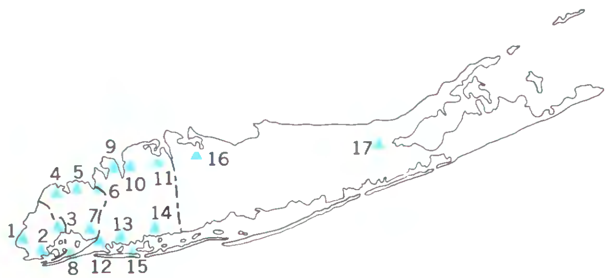


FIGURE 5. Major sewage-treatment plants.

IDENTIFICATION OF
SEWAGE-TREATMENT PLANTS

1 Owls Head
2 Coney Island
3 26th Ward
4 Bowery Bay
5 Tallmans Island
6 Belgrave Dist.
7 Jamaica
8 Rockaway
9 Port Washington
10 Glen Cove
11 Oyster Bay
12 Cedarhurst
13 Nassau County Sewer Dist. No. 2
14 Freeport
15 Long Beach
16 Huntington
17 Riverhead

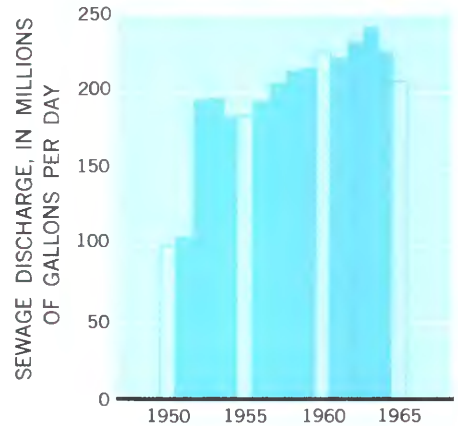


FIGURE 1. Treated sewage discharged from Kings County. (Water from upstate sources.)

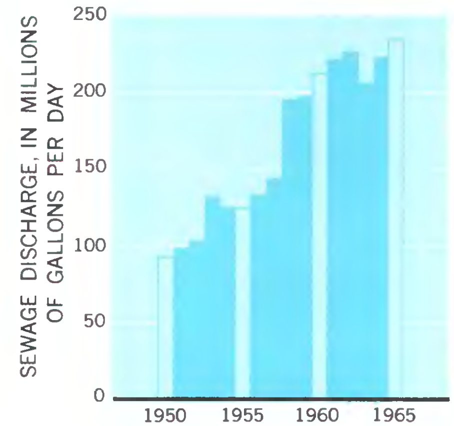


FIGURE 2. Treated sewage discharge from Queens County. (Water mostly from upstate sources, partly from local wells).

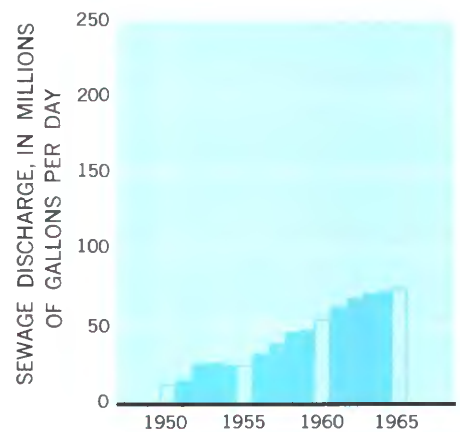


FIGURE 3. Treated sewage discharged from Nassau County. (Water from local wells.)

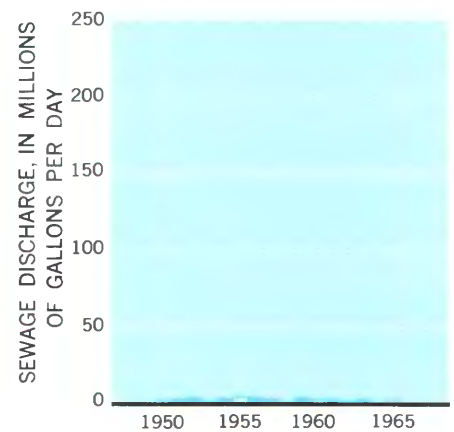


FIGURE 4. Treated sewage discharged from Suffolk County. (Water from local wells.)

Recharge basins

The more than 2000 recharge basins on Long Island (or "sumps", as they are frequently called locally) represent one of the major and one of the most readily apparent modifications of Long Island's natural hydrologic regimen that has resulted from the activities of man. Practically all the basins are unlined excavations in the upper glacial deposits; they range from about 10 to 20 feet in depth and from less than 1 to about 30 acres in area.

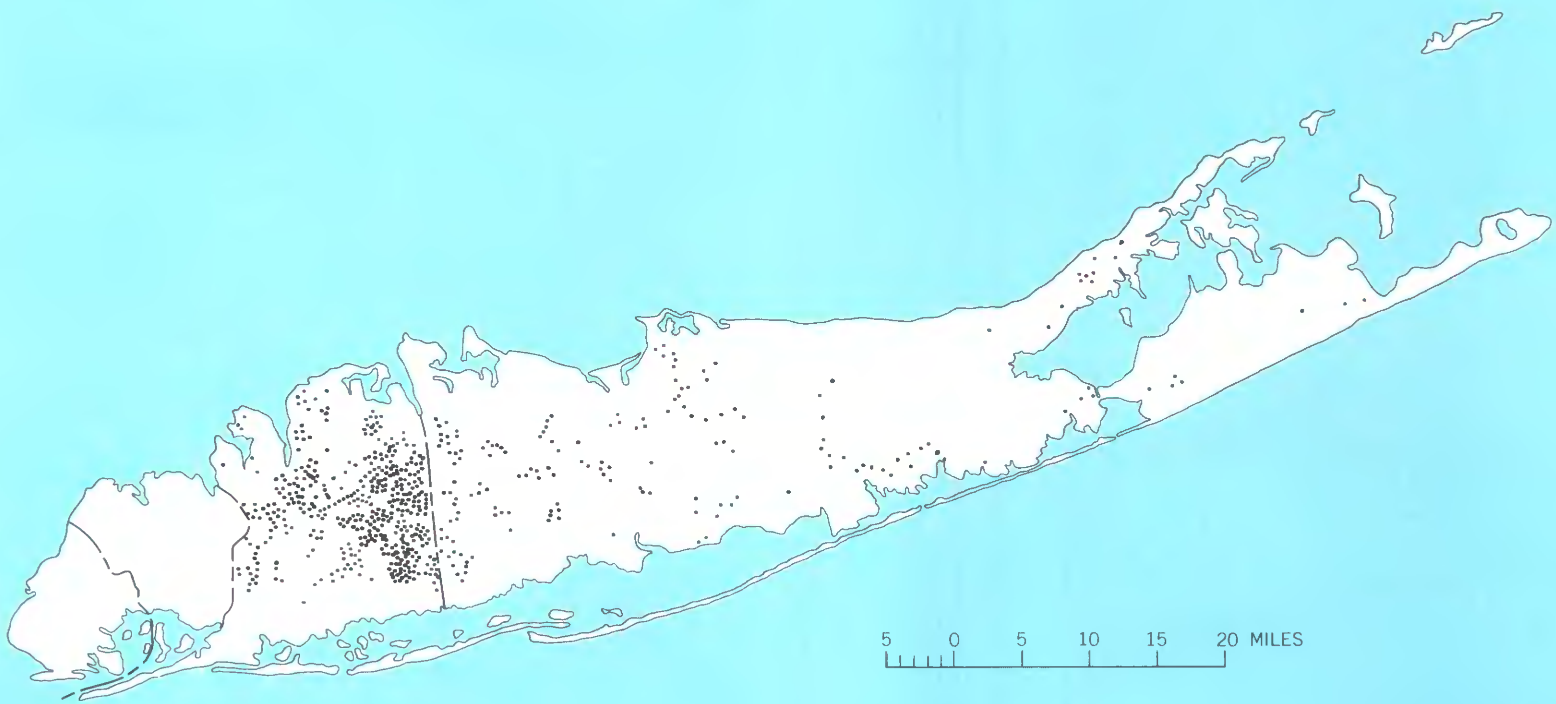
The principal function of the basins is the disposal of direct runoff in an efficient and economical manner. Urbanization, notably the construction of buildings and paved surfaces, has significantly reduced the permeable surface area available for the natural infiltration of precipitation, and thereby has locally increased direct runoff. Rather than a network of large and extensive storm sewers to the sea to accommodate the increased runoff, a system of short storm-sewer lines leading to recharge basins has been constructed in Nassau and Suffolk Counties. In the past two decades, most new housing developments in these counties have been required to include construction of one or more basins, the size and number of which are related to the size of the newly created impervious area and the size of the drainage area. Likewise, most of the highway drainage in these counties is accomplished by means of recharge basins.

Recharge basins are generally used only where the water table is sufficiently deep to remain below the floors of the basins at least most of the time. Therefore, sizable nearshore areas where the water table is within a few feet of the land surface, especially on the south side of the island, do not have recharge basins and are drained by natural channels or the more convential ditches and covered pipes emptying into adjacent salt-water bodies.

As shown on the accompanying map (pl. 7F) Nassau County has the largest number and greatest density of basins, reflecting the intensive suburban development of that county. Kings and Queens Counties have not adopted recharge basins, and most of the storm runoff in these counties is discharged by sewers directly into the sea.

Most of the water entering the recharge basins infiltrates into the ground fairly rapidly (commonly within a day or so), and most of it ultimately recharges the ground-water reservoir. The relation of natural ground-water recharge in a given area to the recharge in that same area after construction of impervious structures and recharge basins has not been fully evaluated. Investigations to date (Brice and others, 1959, and Seaburn, oral communication), however, suggest that recharge has not been decreased materially and may be somewhat increased where urbanization has been accompanied by construction of these basins. There is little doubt, however, that if the increased direct runoff in urbanized areas was discharged into the sea rather than into recharge basins, ground-water recharge would be significantly decreased.

PLATE 7F
LOCATION OF RECHARGE BASINS
ON LONG ISLAND, NEW YORK,
IN 1965



Diffusion wells

In 1933, the New York State Legislature enacted a water-conservation law to protect the ground-water resources of Long Island. The law empowered the New York State Water Power and Control Commission (and subsequently, the New York State Water Resources Commission) to regulate the construction of all wells on Long Island that withdraw more than 100,000 gpd (gallons per day) from the ground-water reservoir. In 1954, the law was modified to include all wells having capacities of more than 45 gpm (gallons per minute) or about 65,000 gpd.

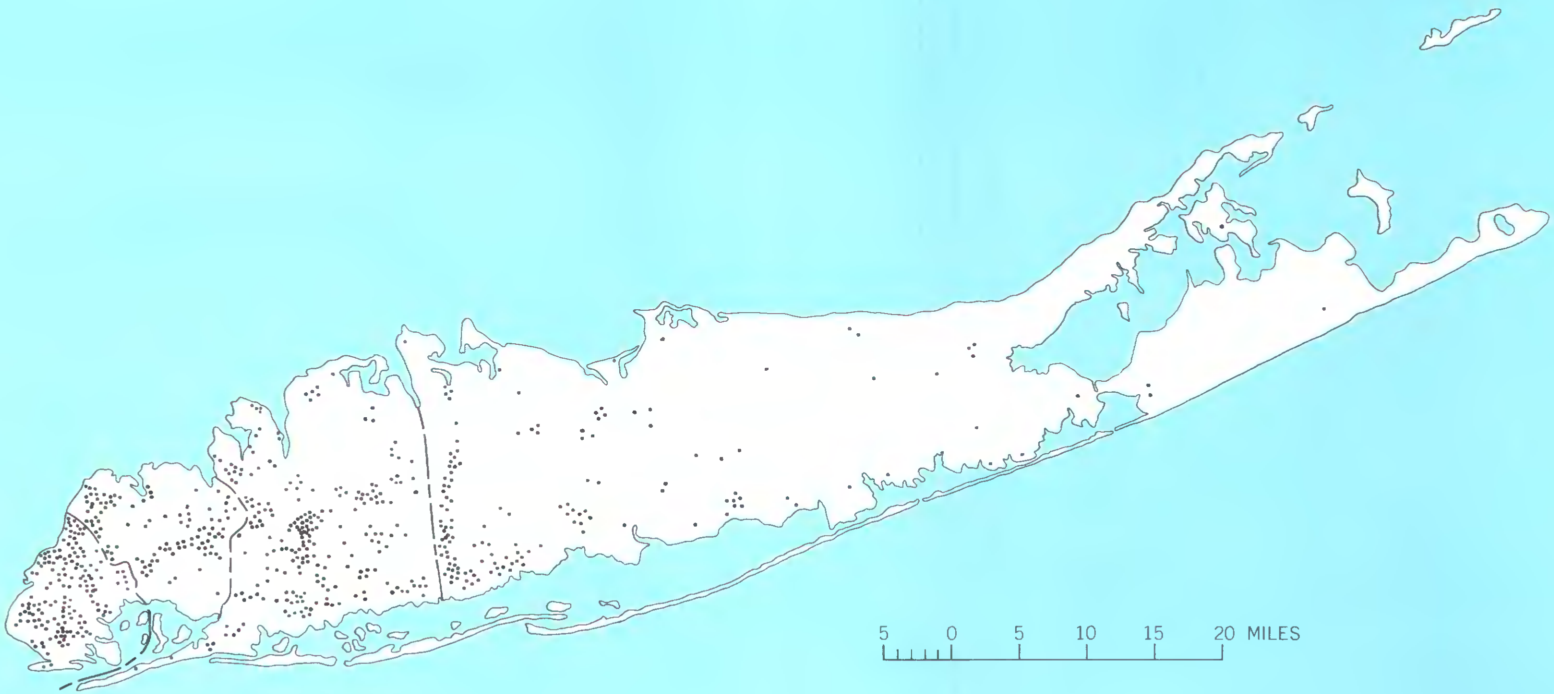
The state regulatory agency established a general policy in 1933 prohibiting, "***the drilling of new industrial wells with capacities in excess of 69.4 gpm (100,000 gpd), unless the water pumped is returned in an uncontaminated condition into the ground through diffusion wells or other approved structures" (Johnson, 1948, p. 1160–1161). The term diffusion well as used on Long Island is virtually identical to the more widely used terms artificial recharge well or injection well.

Presently, more than 1,000 diffusion wells, many of which are shown on the accompanying plate (pl. 7G) return used ground water to the ground-water reservoir of Long Island. According to unpublished data supplied by the New York State Water Resources Commission, an average of about 46 mgd was injected into diffusion wells on Long Island during 1965, including about 13.4 mgd in Kings County, 11.1 mgd in Queens County, 14.2 mgd in Nassau County, and 7.5 mgd in Suffolk County. Most of the water had been used for air conditioning, and its temperature was markedly raised, before it was returned to the ground-water reservoir.

The diffusion wells on Long Island vary considerably in capacity, depth, and method of construction. Most extend into the zone of saturation, but some do not penetrate beyond the zone of aeration. (The latter commonly are called "dry" diffusion wells.) Many of the older diffusion wells were shallow dug pits (commonly 10 or 20 feet in depth) that were lined with wood or brick cribbing or with torch-slotted, large-diameter (30- to 36-inch) steel pipe. More recently, diffusion wells several hundred feet or more in depth have been constructed using the most modern well-drilling techniques and materials, including drilling the wells by the reverse hydraulic-rotary method, and equipping them with wire-wrapped stainless-steel screens and fiberglass casings.

The more successful diffusion wells on Long Island reportedly accept water at rates of more than 500 gpm initially. With continued use, however, the injection capacity of these wells tends to decrease as a result of clogging, and most of the wells require periodic maintenance.

PLATE 7G
LOCATION OF DIFFUSION WELLS
ON LONG ISLAND, NEW YORK,
IN 1960



Changes in ground-water temperature

Substantial quantities of warm water are returned to the ground-water reservoir of Long Island through diffusion wells, cesspools, and septic tanks. Inasmuch as the cool, relatively constant temperature of the ground water is a desirable characteristic for many purposes (for industrial air-conditioning, for example), the increase in temperature resulting from the activities of man (thermal pollution) is of considerable concern.

Brashears (1941) described a case history of thermal pollution resulting from recharge, through a diffusion well, of water used for manufacturing ice in Kings County in the late 1930's and the early 1940's. Water was withdrawn from supply well K131, used in the ice plant, and then returned through diffusion well K314 (fig. 2, pl. 7H). Well K131 was screened in the upper glacial aquifer at a depth of about 150 feet; well K314 was about 300 feet distant, and was screened at about the same depth. At the time of the study (1937–1940) the nearest other recharge well was more than a mile away.

Prior to development, the temperature of the shallow ground water was about 52–56°F. In 1937, water was withdrawn from well K131 at an average rate of about 1.4 mgd, and was returned to the ground-water reservoir through diffusion well K314 at a rate of about 1 mgd. The maximum temperatures of the recharge water in the summers of 1937 and 1938 were about 82°F and 84°F, respectively. By July 1938, a net rise of 14°F was noted in the temperature of the water from well K131. Recharge through well K314 decreased to an average of 0.2 mgd in 1938–40, and the temperature of the recharge water also decreased. As a result, the temperature of the water from well K131 also decreased markedly.

Reportedly, widespread thermal pollution to the extent described above is not common on Long Island (DeLuca, Hoffman, and Lubke, 1965, p. 5). Locally, however, it causes considerable difficulty where ground water is withdrawn for industrial cooling or air-conditioning and is returned to the ground-water reservoir through diffusion wells.

Small increases in the temperature of the shallow ground water have been noted in the vicinity of suburban housing developments. For example, Pluhowski and Kantrowitz (1964, p. 65–66) showed that the average annual temperature of shallow ground water in a wooded area near Champlin Creek is 1–4°F cooler than ground-water temperatures at comparable depths in a nearby residential area (fig. 3, pl. 7H). They attributed most of the difference to the fact that absorption of solar energy by soils in the residential area was greater than that in the wooded area because of the comparative absence of shade and because of the absence of an insulating layer of organic material in the residential area. They further postulated that the small contributions of warm water from cesspools in this specific area probably had little effect on the temperature of the shallow ground water.

PLATE 7H
EFFECTS OF MAN'S ACTIVITIES ON THE TEMPERATURE OF GROUND WATER ON LONG ISLAND, NEW YORK

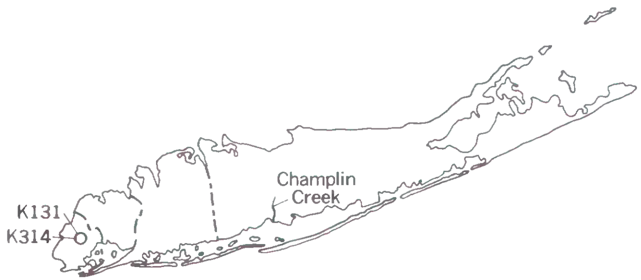


FIGURE 1. Location of wells K131 and K314 in Kings County, and Champlin Creek in Suffolk County.

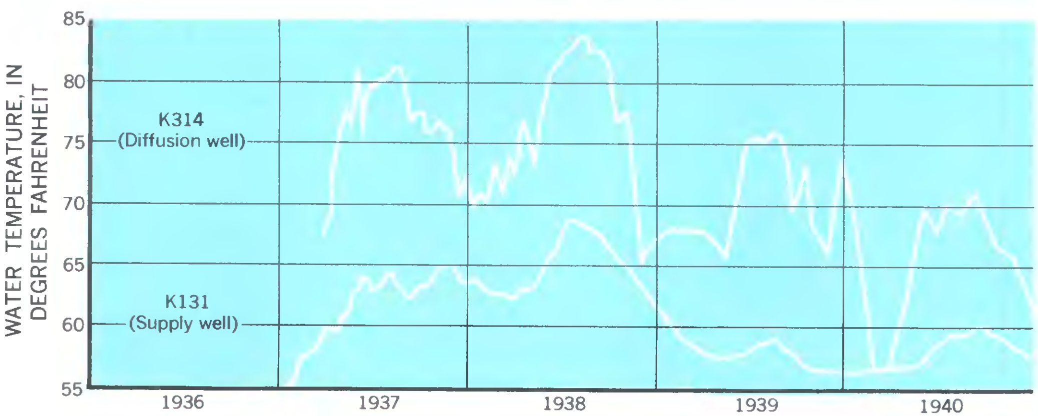


FIGURE 2. Effects on the temperature of water in well K131 of injecting warm water into well K134, Kings County. (After Brashears, 1941, fig. 2.)

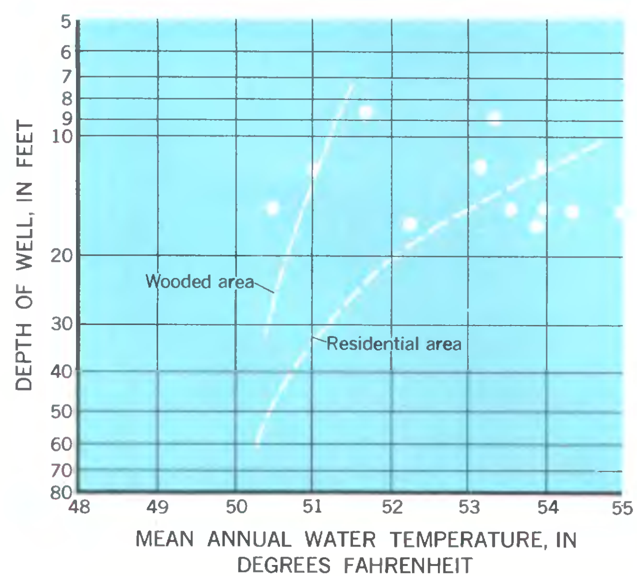


FIGURE 3. Relation of ground-water temperature to depth of wells near Champlin Creek. (After Pluhowski and Kantrowitz, 1964, fig. 19.)

8 MAJOR WATER PROBLEMS RESULTING FROM THE ACTIVITIES OF MAN

Some effects of pumping the ground water

Some of the major water problems that have resulted from the activities of man on Long Island are declining ground-water levels, contamination of the fresh ground-water reservoir with salty water, and contamination of the fresh ground water with domestic and industrial pollutants. These problems are reviewed briefly in this chapter. Other important water problems, such as those concerned with shipping and navigation, or with pollution of some of the bays and the resulting harmful effects on the shell-fish industry, are beyond the scope of this report.

When water is withdrawn from a well, either by pumping or by allowing certain wells to flow, the ground-water reservoir responds in several ways. Two short-term effects of pumping ground water have caused considerable concern locally: (1) Declining ground-water levels in the vicinity of pumping wells, and (2) increasing chloride content of the water pumped from some wells.

In general, the extent and magnitude of drawdown (decline in ground-water levels) in the vicinity of a pumping well (fig. 1, pl. 8A) depends upon complex relations between (a) the rate and duration of pumping, (b) the distance from the pumping well to the point of observation, and (c) the hydraulic properties of the aquifer. Figure 3 of the accompanying plate shows the relation between pumpage from the so-called Massapequa infiltration gallery, which is used occasionally to withdraw water from the upper glacial aquifer and drawdown in well N1222. Well N1222 is a 29-foot deep observation well that also taps the upper glacial aquifer and is about 400 feet from the infiltration gallery (Perlmutter and Geraghty, 1963, p.73). Periods of greatest pumping from the infiltration gallery correspond closely with periods of maximum drawdown in the well; similarly, when pumping ceases, ground-water levels recover rapidly.

As a result of drawdown in the vicinity of a pumping well and the resulting steep hydraulic gradient toward the well (fig. 1), the chloride content of water from wells in or near the zone of diffusion between fresh and salty water may increase markedly when such wells are pumped. An example is the water pumped from well Q2289 (fig. 4, pl. 8A) which is pumped seasonally; pumping normally begins in March or April and ends in October or November. The well, which is 147 feet deep, taps the upper glacial aquifer and the Jameco aquifer. Before pumping begins, the chloride content of the water is normally about 20 ppm. As the pumping season progresses, the zone of diffusion moves farther and farther inland in response to the withdrawal of fresh ground water and the concurrent lowering of ground-water levels. The inland movement of the zone of diffusion causes the chloride content of the pumped water to increase to 200–300 ppm in midsummer, when pumpage is greatest. In the fall, as pumping decreases, the zone of diffusion moves seaward and the chloride content of the pumped water decreases.

It is to be expected that, in addition to seasonal increases, the chloride content of the water withdrawn from the well eventually will increase progressively over the years unless preventive measures are taken. The likelihood of this long-term increase occurring will be greater if additional ground water is withdrawn from this well or from nearby wells.

Because the saturated deposits on Long Island commonly are much more permeable in the horizontal direction than in the vertical direction, the effects of pumpage ordinarily are greater in the horizontal direction. For example, the decline in ground-water levels caused by a pumping well may be hundreds or thousands of times greater at a given distance laterally from the well than the decline in ground-water levels at the same distance vertically above or below the zone tapped by the well.

PLATE 8A
SOME EFFECTS OF PUMPING THE GROUND WATER ON LONG ISLAND, NEW YORK

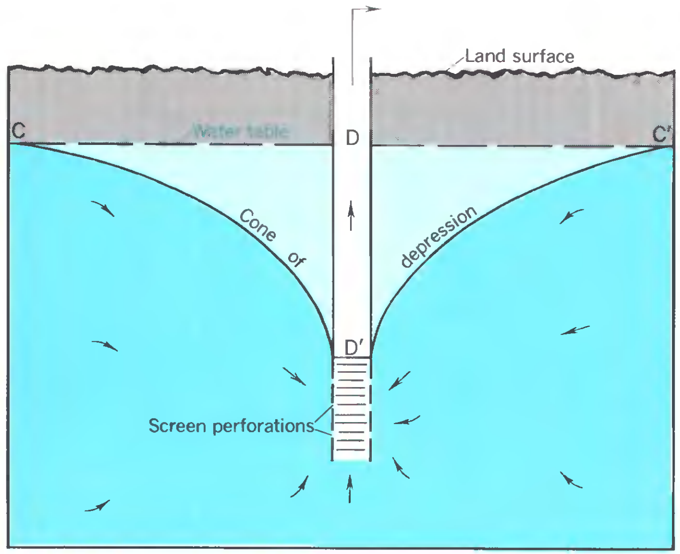


FIGURE 1. Diagrammatic section through a discharging water-table well. C–D′–C′ is a section through the cone of water-table depression. D–D′ represents the drawdown from the static (nonpumping) water level. Arrows indicate direction of water movement.

FIGURE 2. Location of wells N1222 and Q2289.

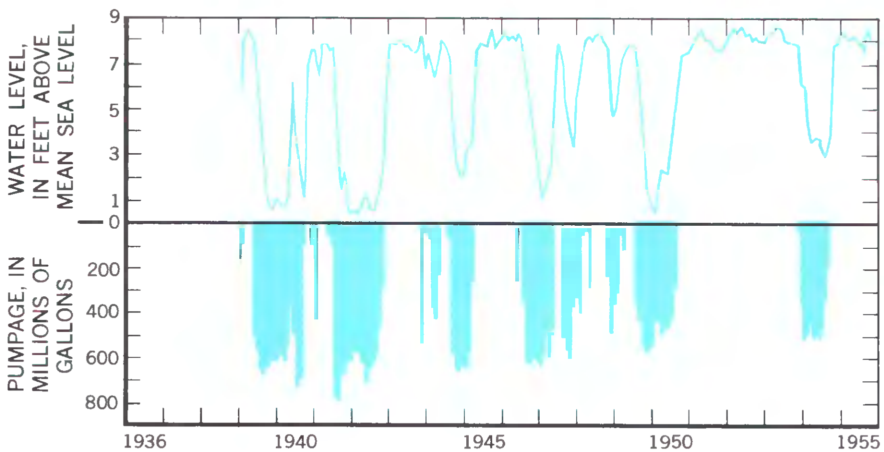


FIGURE 3. Relation between pumpage from the Massapequa infiltration gallery and water levels in nearby well N1222.(Adapted from Perlmutter and Geraghty, 1963, fig. 15.)

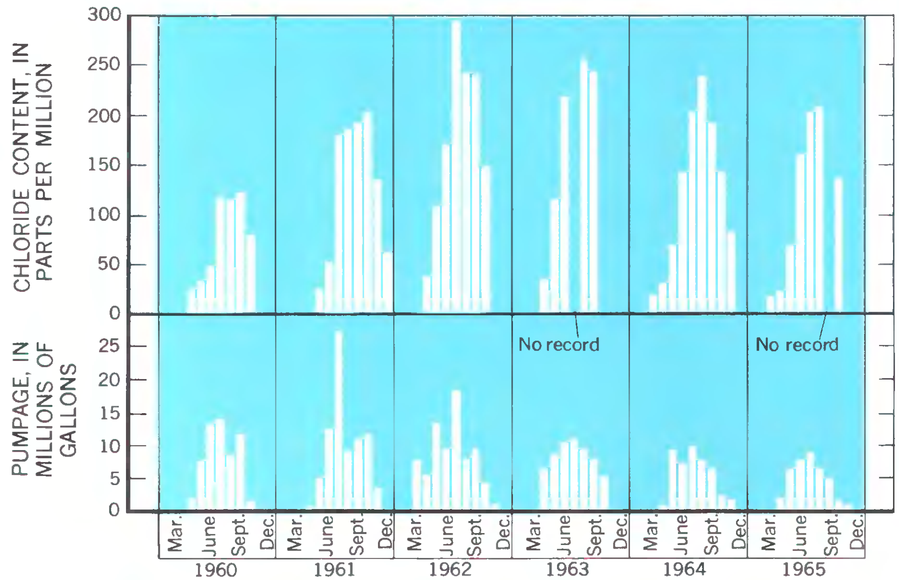


FIGURE 4. Relation between monthly pumpage and Chloride content of water pumped from well Q2289.

Problems associated with major changes in ground-water levels in Kings and Queens Counties

In the past 60 years, intensive ground-water development has caused major changes in the altitude of the water table in Kings and Queens Counties. The 1903 water-table contour map shown in figure 1 on the accompanying plate (pl. 8B) is based on the earliest available water-level data. Nevertheless, even these contours reflect the impact of ground-water development because net pumpage at the time was already substantial. In Kings County, for example, net pumpage averaged about 28 mgd (Lusczynski, 1952, p. 4). In 1903, ground water flowed westward from Nassau County into the northeast part of Queens County. Elsewhere in Kings and Queens Counties, ground-water flow was toward the bordering shore lines.

By the early 1930's, net ground-water withdrawals for public-supply and industrial use in Kings County exceeded 75 mgd. In addition, natural ground-water recharge had decreased substantially because much of the permeable soil had been covered with impermeable surfaces such as streets, highways, and buildings. These factors resulted in a marked imbalance in the ground-water system—ground-water discharge exceeded recharge, causing a net decrease in the amount of fresh ground water in storage. The decrease in storage was evidenced by declining ground-water levels.

In 1936 the water table in practically all of Kings County had declined below sea level (fig. 2, pl. 8B); locally it had declined about 50 feet to a depth of more than 35 feet below sea level. As a result, a landward hydraulic gradient had developed causing salty water from the sea to invade the fresh ground-water reservoir.

As wells in Kings County became contaminated with salty water, more and more of the county was supplied with water obtained from upstate New York sources through the New York City public-supply system. By 1947, all pumpage of ground water in Kings County for public-supply use was discontinued. In addition, the mandatory use of diffusion wells, which returned water used for air conditioning and other purposes to the ground-water reservoir, resulted in the conservation of large amounts of ground water. Because of these factors, ground-water levels in Kings County began to recover substantially in the early 1940's. By 1965, when gross pumpage was about 24 mgd and net pumpage probably was about 10 mgd, the water table in all but the northern part of Kings County had recovered to a position above sea level (fig. 3, pl. 8B). Locally, the rising water table has caused considerable seepage into subways and other subsurface structures that were built when the water table was low in the 1920's and 1930's.

Ground-water pumpage has continued to increase in Queens County during the period in which it decreased in Kings County (from the late 1930's to the present). As a result, the water table in Queens County locally has declined to a level more than 10 feet below sea level (fig. 3, pl. 8B), and salty water has begun to invade the ground-water reservoir in the southwestern part of the county.

PLATE 8B

CHANGING GROUND-WATER LEVELS IN KINGS AND QUEENS COUNTIES, LONG ISLAND, NEW YORK, 1903, 1936, AND 1965

EXPLANATION

—10—

WATER-LEVEL CONTOUR
Shows altitude of water level.
Contour interval 5 and 10 feet.
Datum is mean sea level

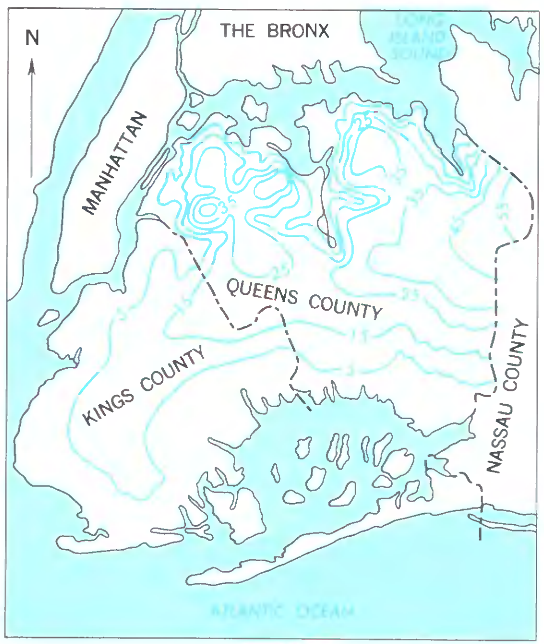


FIGURE 1. Ground-water levels in 1903. (After Lusczynski, 1952.)

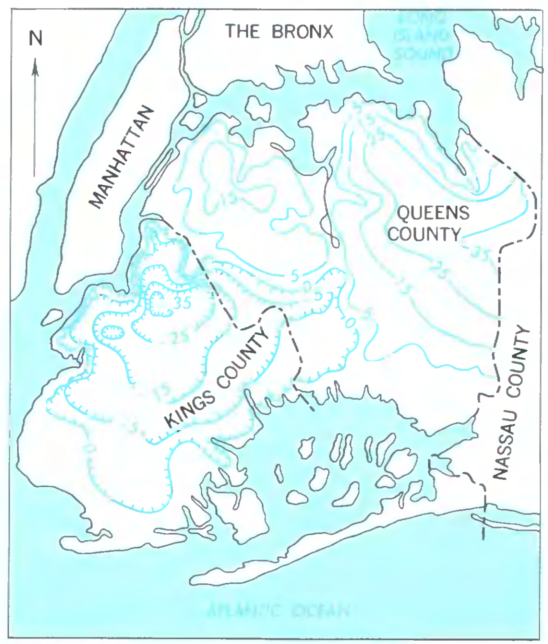


FIGURE 2. Ground-water levels in 1936. (After Suter, 1937.)

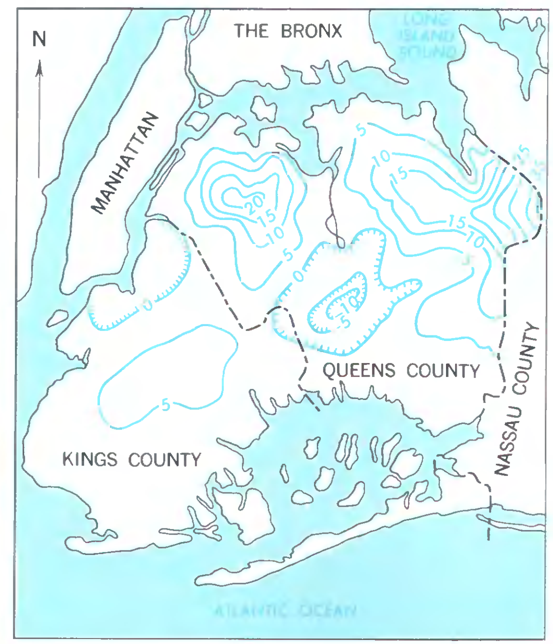


FIGURE 3. Ground-water levels in 1965. (Adapted from an unpublished map prepared by the New York State Water Resources Commission, 1966.)

1 0 1 2 3 4 MILES

Salty ground water in southeastern Queens and southwestern Nassau Counties

Contamination of well water by salty ground water in southwestern Nassau and southeastern Queens Counties has been the cause of considerable concern and, therefore, the subject of intensive study. (See Perlmutter and Geraghty, 1963; Lusczynski and Swarzenski, 1966). Three major tongues or wedges of salty ground water are found in the area: (1) a shallow unconfined wedge in the upper glacial aquifer, (2) an intermediate confined wedge in the Jameco aquifer and in the upper part of the Magothy aquifer, and (3) a deep confined wedge in the Magothy aquifer and in the Raritan clay (pl. 8C).

For the most part, the position of the shallow wedge of salty ground water has not changed significantly during historic time. The intermediate and deep bodies of salty ground water, however, are actively advancing landward. Pumpage from the Jameco and Magothy aquifers within the area shown in figures 1 and 2 of plate 8C is presently more than 100 mgd, and much of this pumpage is ultimately discharged to the sea through sewage-treatment plants. As a result, total recharge to the Jameco and Magothy aquifers presently is less than the combined natural and artificial discharge and, therefore, the amount of fresh ground water in storage in the area is decreasing. Much of the decrease in the amount of fresh ground water in storage is being compensated for by an increase in the amount of salty ground water in storage. In other words, as the hydraulic heads in the fresh ground-water body are decreasing, salty ground water is moving inland.

Lusczynski and Swarzenski (1966, p. 50–52) estimated that the deep salty-water wedge has moved inland an average of about 1,000 feet (at rates ranging from 10 to 50 feet per year) since the early 1900's; locally, however, in the vicinity of some well fields, the deep salty-water wedge has moved more than a mile inland since 1952, at a rate of about 300 feet per year. Lusczynski and Swarzenski (1966, p. 55) also noted that, on the average, the intermediate salty-water wedge has moved inland less than 1,000 feet since the early 1900's.

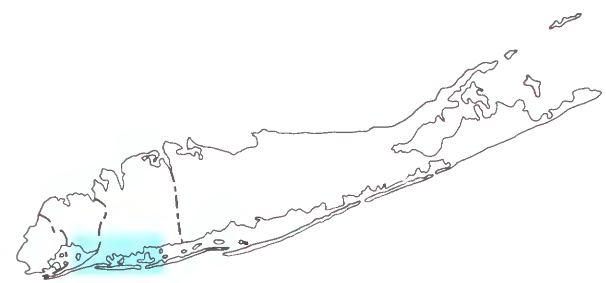


FIGURE 1. Location of the area shown in figure 2.

PLATE 8C
OCCURRENCE OF SALTY GROUND WATER IN SOUTHEASTERN QUEENS AND SOUTHWESTERN NASSAU COUNTIES, LONG ISLAND, NEW YORK, IN 1961
(Adapted from Lusczynski and Swarzenski, 1966, pl. 5.)

EXPLANATION

Approximate landward limit of intermediate salty-water wedge

Approximate landward limit of deep salty-water wedge

WATER-LEVEL CONTOUR
Shows altitude of water level. Contour interval 1 and 10 feet. Datum is mean sea level.

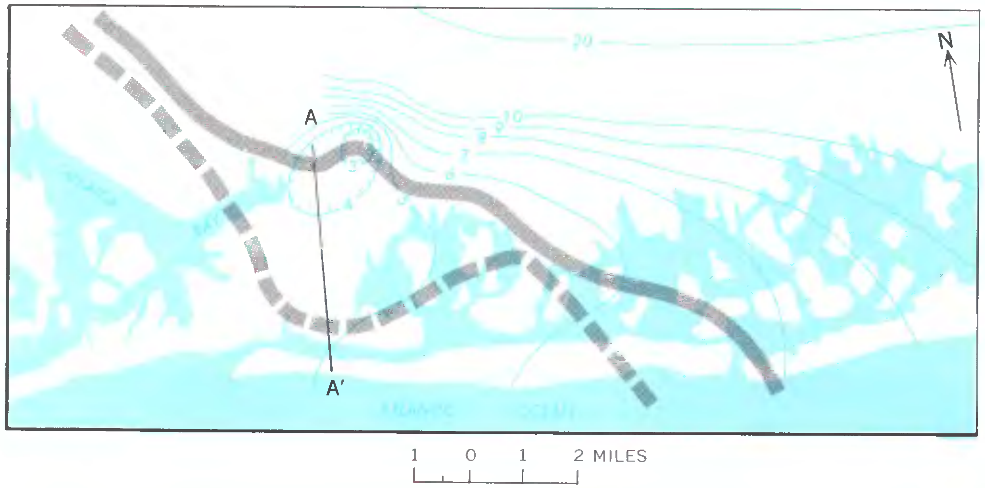


FIGURE 2. Occurrence of salty ground water. Section A–A′ shown on figure 3.

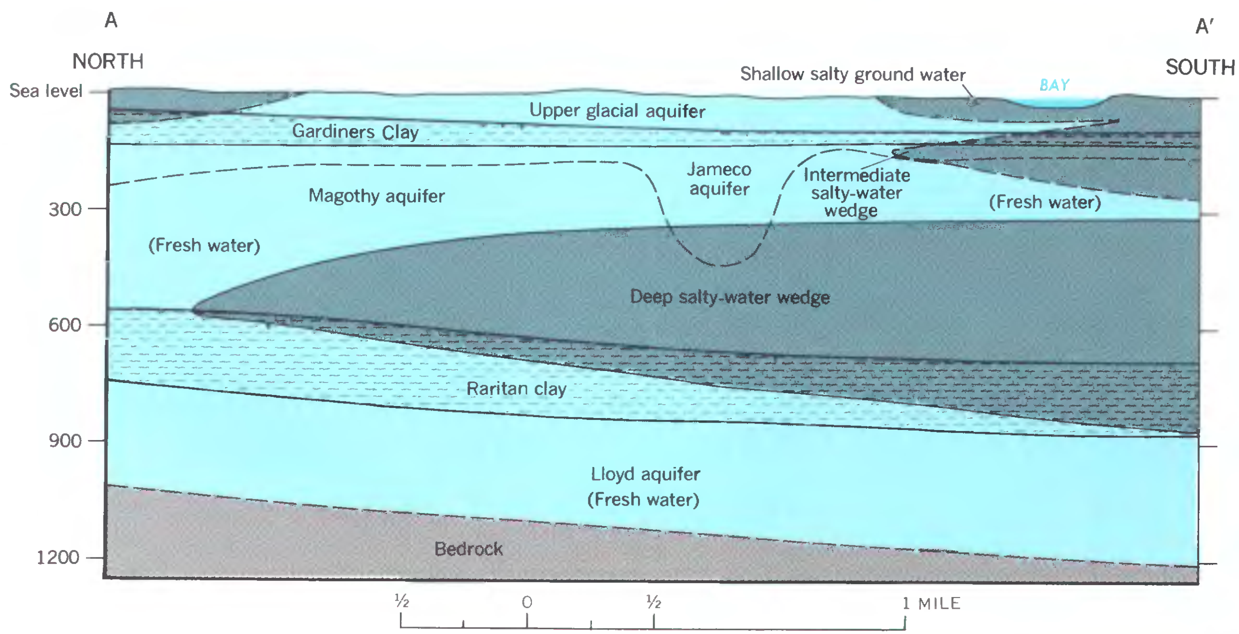


FIGURE 3. Occurrence of salty ground water.

Contamination of shallow ground water with ABS

Seepage of domestic waste water from thousands of cesspools on Long Island has contaminated the shallow ground water in many of the intensely developed suburban parts of Nassau and Suffolk Counties. Unusually high concentrations of such constituents as chloride, nitrate, sulfate, and phosphate, and also bacteria are commonly found in shallow ground water polluted with cesspool effluent. Foaming of ground water withdrawn from the shallow upper glacial aquifer that is contaminated with cesspool effluent also has occurred. The foaming generally has been caused by ABS (alkylbenzenesulfonate), a chemical compound used in many household detergents for the past 15 years or so. ABS is not considered toxic in the quantities commonly found in ground water. However, the U.S. Public Health Service (1962) recommends that, because the presence of this substance may indicate cesspool contamination, the concentration of ABS in water used for domestic purposes should not be more than 0.5 ppm.

The contamination of ground water by detergents in the South Farmingdale area was studied by Perlmutter, Lieber, and Frauenthal (1964). At the time of the study (1962), the area was not served by a communal sewer system, and domestic wastes from about 250 homes were disposed of through individually owned cesspools or septic tanks. The area is underlain by moderately permeable upper glacial deposits about 80–130 feet thick, which in turn overlie the Magothy aquifer. The water table ranges from 15 feet below land surface to less than a foot below the surface near Massapequa Creek; the general direction of ground-water movement is southward (fig. 2, pl. 8D).

The lower limit of contamination shown in figure 3, plate 8D, was defined by ground water having ABS concentrations of 0.1 ppm. Perlmutter, Lieber, and Frauenthal (1964, p. 173) report that the determinations of ABS in the samples obtained from the contaminated zone ranged from 0.02 ppm to 32 ppm, and that the ABS concentrations in the cesspools might have been as high as 60 ppm. However, they note that most of the samples tested had less than the amount of ABS that would cause the water to foam when agitated—about 1 ppm.

In 1962, the contaminated ground water reportedly was moving slowly southward at a rate of about 1 foot per day. Some of the water was discharging into Massapequa Creek, and some was flowing southward beneath the creek. There was no evidence to suggest that the pollutants had moved downward into the Magothy aquifer.

ABS is a moderately stable chemical compound, and may remain in the ground water for long periods of time. Without additional input of ABS, however, natural dilution in a contaminated area ultimately could reduce the concentration of ABS below detectable levels. Substitute compounds that are more subject to breakdown by bacteria in the presence of oxygen are now being sold on Long Island by the soap and detergent industry. New detergents and the sewering of additional large areas which is proposed for the future should help alleviate the ABS contamination on Long Island.

PLATE 8D

CONTAMINATION OF SHALLOW GROUND WATER WITH ABS[1] IN THE SOUTH FARMINGDALE AREA LONG ISLAND, NEW YORK

(Adapted from Perlmutter, Lieber, and Frauenthal, 1964.)

1. Alkylbenzenesulfonate, a compound used in many household detergents.

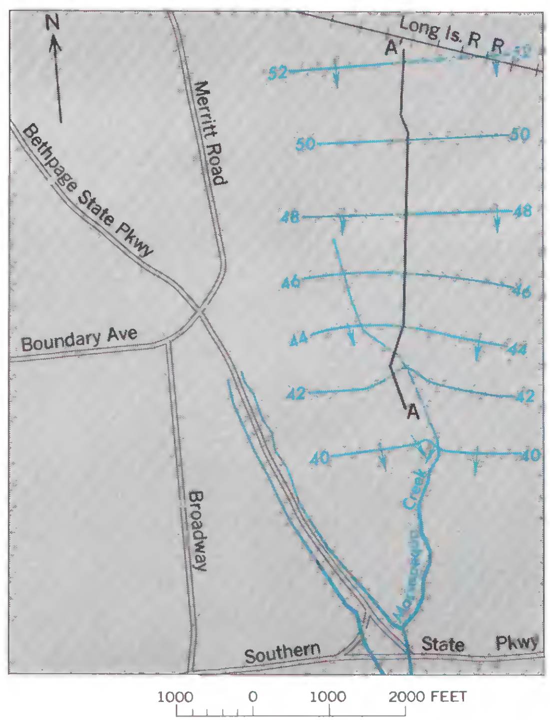


FIGURE 2. Water-table contours in the South Farmingdale area. Arrows indicate the general direction of ground- water flow. Contour interval 2 feet. Datum is mean sea level.

FIGURE 1. Location of the South Farmingdale area.

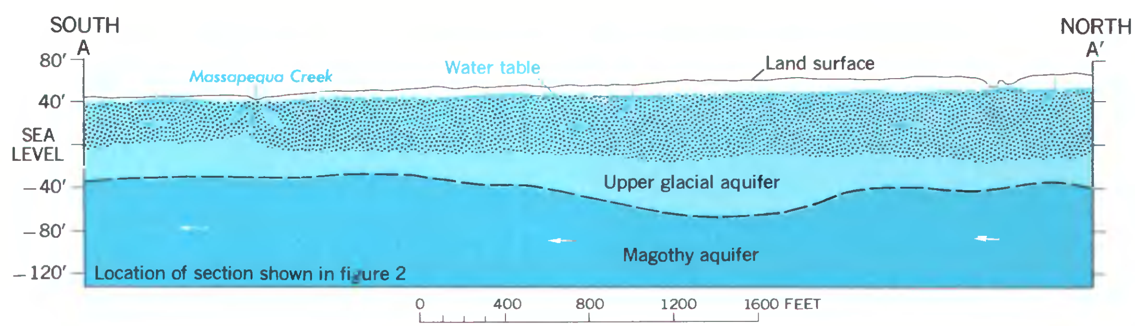


FIGURE 3. Extent of contamination of ground water with ABS. Contaminated water is shaded.

Contamination of shallow ground water with cadmium and chromium salts

Locally, the pollution of shallow ground water with industrial wastes is also a serious problem on Long Island. One particular case of such pollution, in the South Farmingdale area of Nassau County (fig. 1, pl. 8E), has been studied in considerable detail (Davids and Lieber, 1951; Lieber and Welsch, 1954; Welsch, 1955; and Perlmutter, Lieber, and Frauenthal, 1963). The general geologic and hydrologic conditions in the area are described in the preceding section.

In 1962, the plume of contaminated shallow ground water in the South Farmingdale area (figs. 2 and 3, pl. 8E) contained as much as 3.7 ppm of cadmium ions and 14 ppm of hexavalent-chromium ions. Drinking-water standards established by the U.S. Public Health Service (1962) indicate that concentrations of chromium in excess of 0.05 ppm and cadmium in excess of 0.01 ppm are objectionable in public-supply water. Excessive amounts of either constituent in drinking or cooking water may be a health hazard.

Hexavalent chromium and cadmium have been introduced into the shallow ground water as a result of the discharge of industrial metal-plating wastes into shallow disposal (recharge) basins (figs. 2 and 3, pl. 8E). Reportedly, chromium was detected in a shallow supply well at the industrial plating plant as early as 1942. In 1949, a chromium-treatmet facility for the industrial waste water was installed at the plant. Chemical analyses made in 1962 indicate that the plating wastes discharged into the disposal basins contained no detectable hexavalent chromium; however, some samples contained as much as 3.5 ppm cadmium (Perlmutter, Lieber, and Frauenthal, 1963, p. 182).

In 1962, the body of shallow ground water contaminated with chromium and cadmium (figs. 2 and 3, pl. 8E) was about 4,200 feet long and had a maximum width of about 1,000 feet. It was moving southward at a rate of several hundred feet per year, and some of the contaminated ground water was discharging into Massapequa Creek. The maximum measured chromium content of the creek water locally was 2.1 ppm, and the maximum cadmium content was 0.07 ppm. As was the case with ABS, hexavalent chromium and cadmium were not noted in nearby wells tapping the Magothy aquifer.

Concentrations of these two elements at specific sampling points in the contaminated plume of ground water reportedly were lower in 1962 than in previous years. The decrease in concentration may have reflected a combination of several factors—a lesser discharge of the contaminating waste fluids into the disposal basins, dilution of the ground water in the plume by recharge from precipitation, and mixing of the contaminated water with uncontaminated ground water. If and when the discharge of these substances into the ground-water reservoir is discontinued, the body of contaminated water gradually will be diluted and ultimately will be dissipated. The time required for all detectable traces of the contaminants to disappear, however, may be several tens of years or more. (See Perlmutter, Lieber, and Frauenthal, 1963).

PLATE 8E

CONTAMINATION OF SHALLOW GROUND WATER WITH CADMIUM AND CHROMIUM SALTS IN THE SOUTH FARMINGDALE AREA, LONG ISLAND, NEW YORK

(Adapted from Perlmutter, Lieber, and Frauenthal, 1963.)

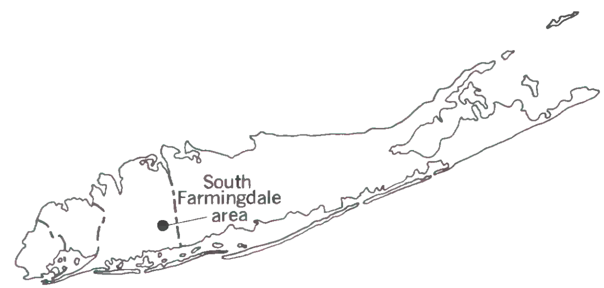


FIGURE 1. Location of the South Farmingdale area.

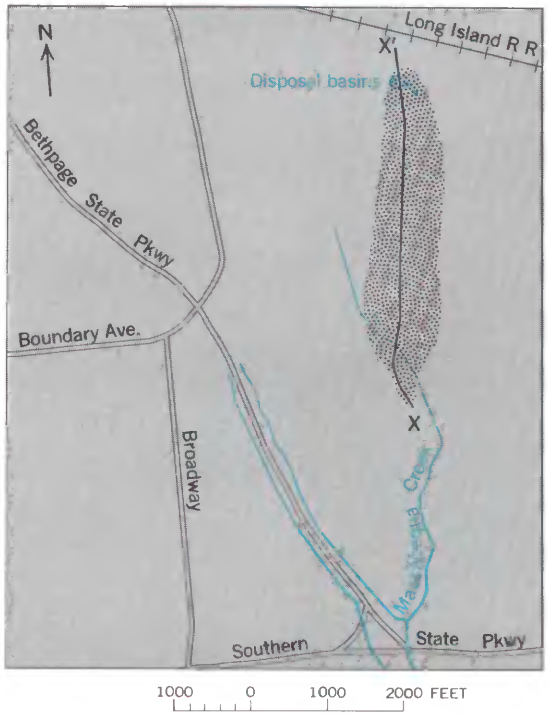


FIGURE 2. Plan view of the plume of ground water contaminated with cadium and chromium.

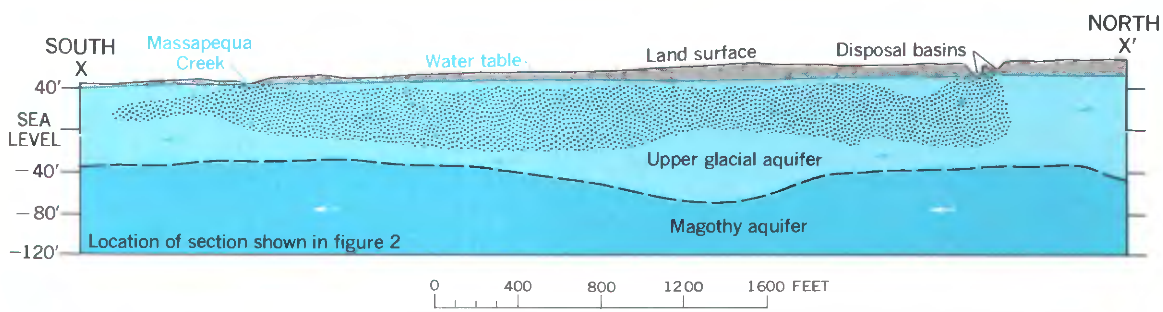


FIGURE 3. Plume of ground water contaminated with cadmium and chromium. Arrows indicate the general direction of ground-water flow. Contaminated water is shaded.

9 ALTERNATIVE METHODS OF DEVELOPING AND MANAGING THE WATER RESOURCES OF LONG ISLAND

The water-budget concept related to water management

Several major alternative methods of developing and managing the water resources of Long Island are presently being proposed by water managers, government officials, and private citizens. Some proposals that already have been made and several others that illustrate pertinent principles are discussed in this chapter of the atlas. Where appropriate, the relation between the proposals and their effects on the "yield" of the system are reviewed.

The final selection of one or more water-management plans for Long Island doubtless will be guided by economic, political, sociological, and other factors, in addition to hydrologic factors. However, an evaluation of any except the hydrologic factors is beyond the scope of this report.

As a prelude to the discussion of the individual alternatives, two basic concepts necessary for effective water management—namely the water-budget concept and the concept of "yield" of the hydrologic system—are discussed briefly.

The hydrologic system of Long Island must respond to any water-management program in a way that is consistent with the water-budget equation:

Inflow = Outflow $\pm$ Change in Storage.

If one of the management objectives is to use the water in a way that will not result in a continued decrease in the amount of fresh ground water in storage, it follows from the equation that a balance between total ground-water inflow (recharge) and outflow must be attained (fig. 1, pl. 9A). That is, increased consumptive use of ground water would have to be balanced by increased inflow (such as artificial recharge) or by a reduction of natural outflow (such as ground-water discharge to streams) to avoid a continuing decrease in the amount of fresh ground water in storage.

A management program that causes a continual hydrologic imbalance wherein the total inflow to the ground-water reservoir is less than the total net outflow (the total quantity permanently lost from the system by evapotranspiration or by discharge to the sea), necessarily will result in the eventual depletion of the fresh ground water in storage (fig. 2, pl. 9A). If, however, the concept of temporary overdraft of fresh water from the ground-water reservoir is incorporated into a management program, the number of management choices increases markedly. For example, increased net ground-water withdrawals from the water-budget area could be accomplished if the decision is made to tolerate (a) declining ground-water levels, (b) the landward movement of salty ground water, (c) decreased streamflow, or (d) a combination of these factors.

The large size of Long Island's fresh ground-water reservoir and its capacity to sustain temporary local overdrafts have permitted the users of ground water on Long Island to weather the severe drought of the 1960's without severe hardships. Equally as important, the very large size of Long Island's ground-water reservoir provides time—time during which the current heavy demands for water can be met while sound water management plans are being formulated, selected, and adopted.

INFLOW=OUTFLOW ± CHANGE IN STORAGE

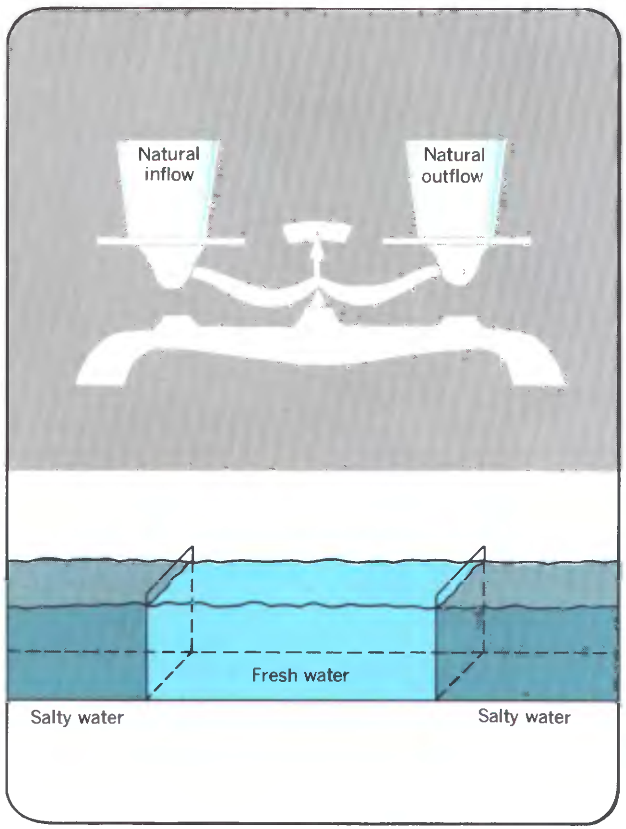


FIGURE 1. The concept of hydrologic balance. Inflow is equal to outflow, and the amount of fresh water in storage remains unchanged.

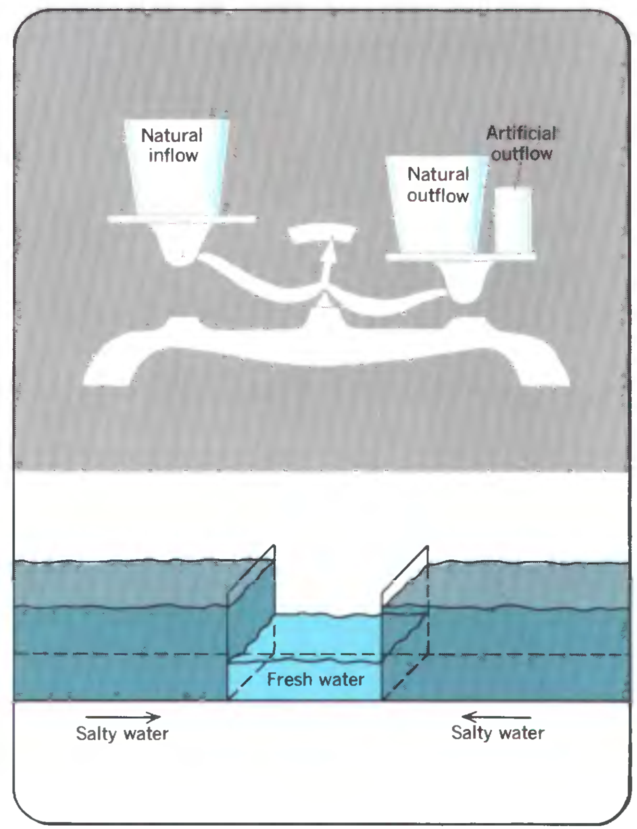


FIGURE 2. The concept of hydrologic imbalance. Outflow exceeds inflow, and the amount of fresh water in storage decreases.

"Yield" of the system

Many individuals and agencies concerned with developing and managing the water resources of the area are interested in the "yield" of all or part of the ground-water system of Long Island. Most commonly, information is desired regarding the "safe yield" of the system, although inquiries also are made about the "perennial yield" or the "natural yield".

Probably the most commonly cited definition of safe yield is that given by Meinzer (1923b, p. 55); he defined safe yield as, "***the rate at which water can be withdrawn from an aquifer for human use without depleting the supply to such an extent that withdrawal at this rate is no longer economically feasible." Todd (1959, p. 200–214) reviewed the concept of safe yield in considerable detail, and redefined the term as follows: "The safe yield of a ground-water basin is the amount of ground water which can be withdrawn from it annually without producing an undesired result." Todd's definition is a more general statement of the concept of safe yield as defined by Meinzer. Although it does not alter the fundamental meaning of the concept, Todd's definition of safe yield broadens its applicability and thereby enhances its usefulness; accordingly, that definition is adopted in this report.

As used by most hydrologists, the term perennial yield is virtually the same as safe yield. The word "perennial" emphasizes the idea that under certain circumstances a ground-water reservoir is capable of perpetually sustaining a specific annual draft (equal to the perennial yield) without causing an undesired effect. The term natural yield has been widely used on Long Island for the past 10–15 years. Commonly, most people who use the term seem to attribute to it a meaning that is similar or identical to that of safe yield.

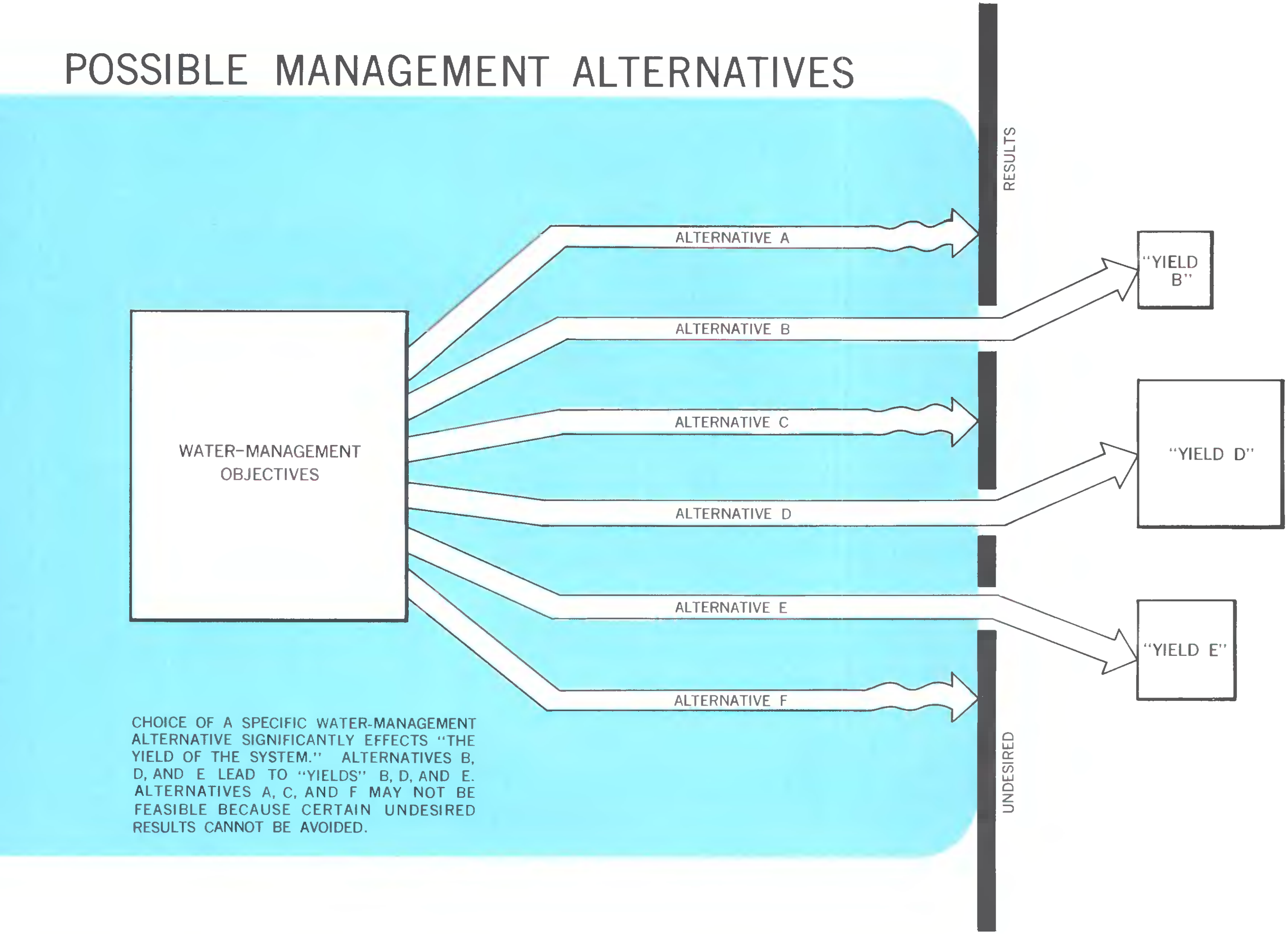
One of the most significant aspects of the concept of the safe yield of any hydrologic system, including the ground-water reservoir of Long Island, is that a quantitative value for safe yield must be determined within the framework of (a) the hydrologic-budget concept, and (b) a precise definition of the undesired results that are to be avoided. Accordingly, the safe yield of any ground-water system is not a single fixed value, but is a variable that depends upon many complexly interrelated factors. For example, if the ultimate depletion of the fresh ground-water reservoir of Long Island is deemed to be an undesired result, then a stage of water-resources development ultimately must be attained at which the total fresh-water inflow (natural plus artificial recharge) to the ground-water reservoir is equal to the total fresh-water outflow (natural plus artificial discharge) therefrom.

Even within the context of this simple example, a specific value for the safe yield of the Long Island ground-water reservoir depends upon which of the many possible methods of management are adopted (pl. 9B). Some methods of management will result in salvaging only small quantities of natural discharge or will cause only an insignificant increase in recharge. Other methods of management, however, will result in salvaging much of the natural discharge and also will induce substantial quantities of additional recharge. The safe yield of the system in the latter case will be many times larger than that in the former case.

In summary, the safe yield of the ground-water reservoir, for all of Long Island or for subareas on the island, can range between large limits depending mainly upon future management decisions regarding (a) the undesired results (hydraulic, water-quality, economic, and other) that are to be avoided, (b) the amount of natural ground-water discharge that is salvaged, and (c) the amount of additional ground-water recharge (natural or artificial) that is induced.

PLATE 9B
"YIELD" OF THE HYDROLOGIC SYSTEM
OF LONG ISLAND, NEW YORK

POSSIBLE MANAGEMENT ALTERNATIVES



CHOICE OF A SPECIFIC WATER-MANAGEMENT ALTERNATIVE SIGNIFICANTLY EFFECTS "THE YIELD OF THE SYSTEM." ALTERNATIVES B, D, AND E LEAD TO "YIELDS" B, D, AND E. ALTERNATIVES A, C, AND F MAY NOT BE FEASIBLE BECAUSE CERTAIN UNDESIRED RESULTS CANNOT BE AVOIDED.

Proposal to continue with the present methods of development and management

One of the several possible future methods of developing and managing the water resources of Long Island is to continue with basically the same procedures that are presently being used (pl. 9C). The major features of the present methods of water-resources development on Long Island are (a) withdrawal of ground water from the shallow unconfined aquifers and from the deeper confined aquifers, (b) artificial recharge with polluted waste water through cesspools and septic tanks, (c) injection of relatively uncontaminated waste water through diffusion wells, (d) artificial recharge with direct-runoff water through shallow basins, (e) discharge of large amounts of treated sewage water (including substantial amounts derived from the ground-water reservoir) into the sea, and (f) importation, for use in Kings and Queens Counties, of large quantities of surface water (about 600 mgd in 1965) derived from upstate sources (not shown on plate 9C).

Most water managers presently assume that practically all the public water supply for Kings and Queens Counties will be derived from upstate sources within about a decade. Conversely, most water managers assume (and many are formulating their plans on the basis of the assumption) that practically all the public water supply for Nassau and Suffolk Counties, for at least the remainder of this century, will be derived from the ground-water reservoir.

Mainly because of hydrologic, economic, and political factors, a large percentage of the total ground-water withdrawals in Nassau and Suffolk Counties in the next several decades probably will be from wells in the water-budget area. At the present time (1966), total fresh-water outflow from the ground-water reservoir within the water-budget area probably is greater than total fresh-water inflow. As a result, the amount of fresh ground water in storage is decreasing, and, locally, the decrease is being reflected by declining ground-water levels and the encroachment of salty ground water into the fresh ground-water reservoir.

If the present management practices continue, it is likely that, within the water-budget area, (a) the hydrologic imbalance will increase, (b) ground-water levels will continue to decline, and (c) salty ground water will continue to move inland. The rate and magnitude of the decline in ground-water levels and the rate of landward movement of salty ground water will be largely related to the magnitude and the distribution of pumpage. If intensive withdrawals are concentrated in relatively small areas, the resulting local decreases in the amount of fresh ground-water in storage will be more than if the withdrawals are equally distributed throughout the water-budget area. However, even in areas where withdrawals are now concentrated, the present average rate of landward movement of salty ground water probably is less than 100 feet per year. Therefore, it seems likely that if the water were to be withdrawn by a carefully spaced network of wells throughout the water-budget area, significantly greater amounts of fresh ground water could be pumped within the area, and the resulting salt-water encroachment probably would not present an insurmountable problem for many decades to come.

If, in the future, increased amounts of waste water are returned to the ground-water reservoir through cesspools and septic tanks, contamination of ground water (especially in the upper glacial aquifer) will increase. Continued increases in the pumpage from the deeper artesian aquifers will accelerate the spread of the contamination in those deeper aquifers. However, if the future increase in withdrawals from the deeper artesian aquifers is no faster than is indicated by the present trends, the quality of most of

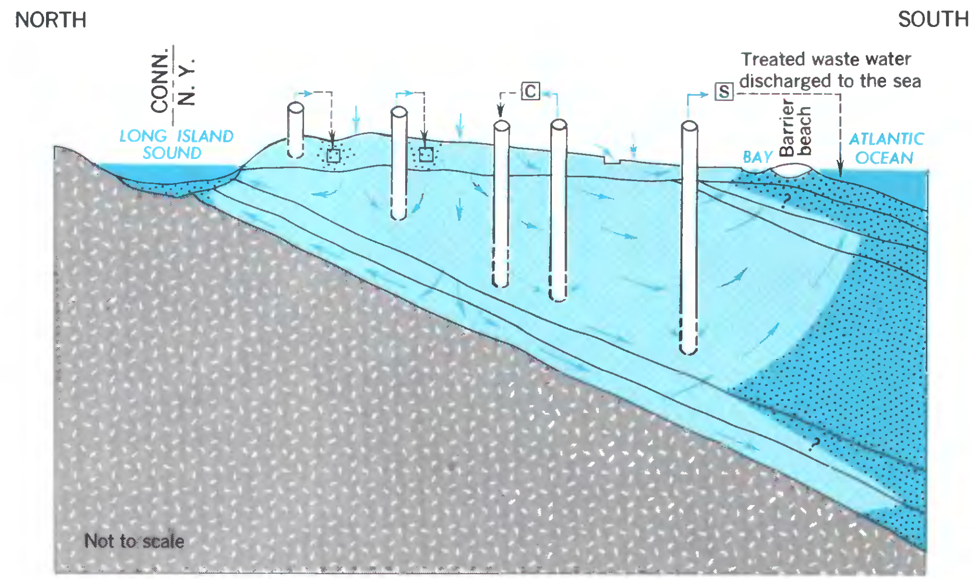
the water in those aquifers probably will not be substantially impaired by cesspool wastes for a long period of time—probably not before salt-water encroachment would have already drastically decreased the available quantity of fresh ground water in storage in the water-budget area.

The slow rate of migration of the contaminants into the deeper aquifers is due mainly to (a) the limited areas in which hydraulic heads in the deeper aquifers are lower than heads in the zones receiving the cesspool wastes (see p. 46A), and (b) the relatively low permeability of the water-bearing materials to water movement in the vertical direction (see p. 46).

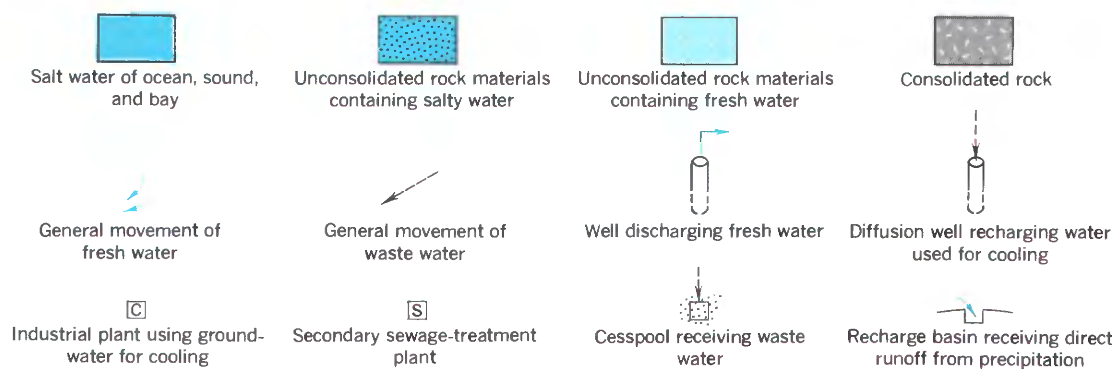
The present management practices, in reality, are equivalent to a method of planned overdevelopment. Eventually, the amount of potable ground water available for withdrawal will decrease markedly, and new sources of water or methods of treating the contaminated water will have to be developed. However, with careful management that treats the ground-water reservoir of the water-budget area as a single hydrologic unit, the useful life of the reservoir (in terms of adequate supplies of potable water) might be more than several hundred years and almost certainly would be more than 50 years, depending on methods and rates of withdrawal and waste disposal.

PLATE 9C

ALTERNATIVE METHOD OF MANAGING THE WATER RESOURCE OF LONG ISLAND, NEW YORK—PROPOSAL TO CONTINUE WITH THE PRESENT METHODS OF DEVELOPMENT



EXPLANATION



Proposal to develop barrier-injection wells

One of the methods of water-resources management that is presently being considered by the Nassau County Department of Public Works is a proposal to alleviate the problem of salt-water intrusion and contamination of the ground-water reservoir by constructing a line of "barrier-injection" wells (pl. 9D) across the entire breadth of Nassau County (about 15 miles), parallel to and near the south shore of the island. The first phase of the proposal is to inject 27 mgd of highly treated sewage-plant effluent into a carefully spaced network of injection wells that will be screened opposite selected layers in the Magothy aquifer. Eventually, barrier-injection wells might be used along both the south shore and the north shore of Long Island, as shown diagramatically on the accompanying plate.

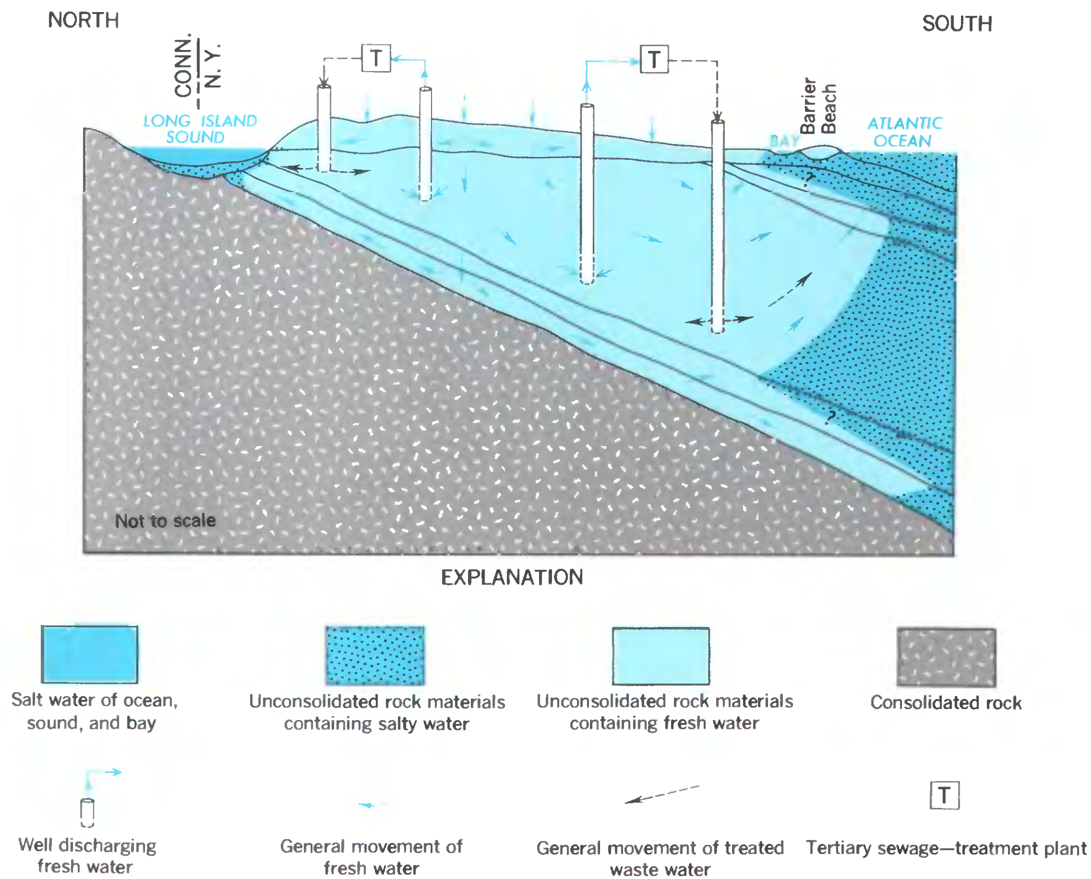
Detailed studies presently are being made cooperatively by the Nassau County Department of Public Works and the U.S. Geological Survey to obtain data needed to evaluate the feasibility of the barrier-injection-well proposal. (See Cohen and Durfor, 1966a and 1966b; and New York State Temporary State Commission on Water Resources Planning, 1966, p. 139–160 and p. 232–244.) These studies are directed mainly toward (a) developing and testing tertiary sewage-treatment procedures and (b) obtaining information regarding the physical and chemical factors that control the rates and injection pressures at which the treated effluent can be injected into the ground-water reservoir, and the nearby hydraulic and geochemical effects of such injection.

If a network of barrier-injection wells ultimately is put into operation, the artesian pressure in the vicinity of each injection well will increase in proportion to the quantity of injected water, and the injected water will move radially away from the well. The seaward hydraulic gradient from the injection well will increase, and a landward hydraulic gradient also will be established. If the wells are properly spaced, the individual mounds of artesian pressure around each well will coalesce, and a pressure ridge will form parallel to the coast. The extent to which the pressure ridge will be effective in preventing the landward movement of salty water will depend upon many complexly interrelated factors, especially (a) the magnitude of the increase in artesian pressure in both the horizontal and vertical directions, and (b) the location and magnitude of nearby ground-water withdrawals from the Magothy aquifer.

Irrespective of the size and shape (and, therefore, the effectiveness) of the pressure ridge formed by injecting 27 mgd into a network of barrier-injection wells, the amount of fresh-water recharge to the ground-water system will be increased by 27 mgd. Accordingly, the safe yield of the system would be theoretically increased by 27 mgd. In practice, however, not all the injected water could be recovered, but a large proportion probably could be salvaged under a careful program of development.

PLATE 9D
ALTERNATIVE METHOD OF MANAGING THE WATER RESOURCES OF LONG ISLAND, NEW YORK—PROPOSAL TO DEVELOP BARRIER-INJECTION WELLS

As suggested in the preceding paragraphs, some of the injected water will move inland toward wells that are withdrawing public-supply water. Eventually, therefore, diluted treated effluent, and under some circumstances undiluted treated effluent, might be withdrawn from nearby pumping wells. For this reason, the sewage-plant effluent that is injected will receive tertiary treatment to upgrade the quality of the water so that it meets or exceeds virtually all the commonly accepted standards for drinking water.



Proposal to develop pumping troughs

Another method that has been mentioned for managing fresh-water aquifers in near-shore areas is the development of so-called pumping troughs (Todd, 1959, p. 284). This method of water-resources conservation, which reportedly will be tested in the field for the first time in California in the near future, is designed mainly to prevent widespread salt-water intrusion into aquifers that are being overdeveloped—that is, aquifers in which fresh water is being replaced by salty water owing to the activities of man.

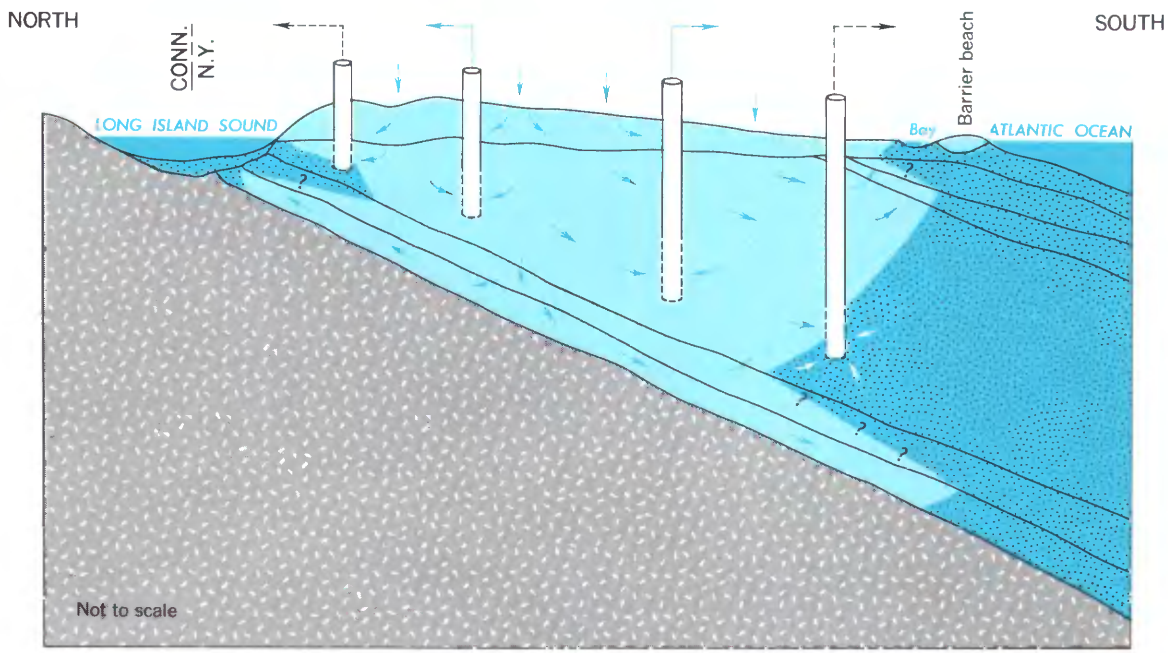
If desired, pumping troughs could be developed by constructing lines of wells parallel to and near the shorelines of Long Island (pl. 9E). Instead of injecting potable water into such wells to create an artesian-pressure ridge, salty ground water would be pumped from the wells to form a trough (or troughs) in the artesian-pressure surfaces. If the pumping created a pressure trough of sufficient size, the salt-water front eventually would stabilize a short distance inland from the pumping trough. The pumping wells that produce the trough would intercept the salty water that ordinarily would have moved inland toward production wells.

The amount of pumpage required to create and maintain a successful pumping trough would depend upon many factors, but most importantly upon the magnitude of the overdevelopment and the desired ultimate position of the stabilized salt-water front. In general, the amount of pumpage required to maintain a successful pumping trough will be proportional to the amount of overdevelopment, and will be inversely proportional to the distance that the salt-water front is permitted to move inland (Harder and others, 1953, p. 9).

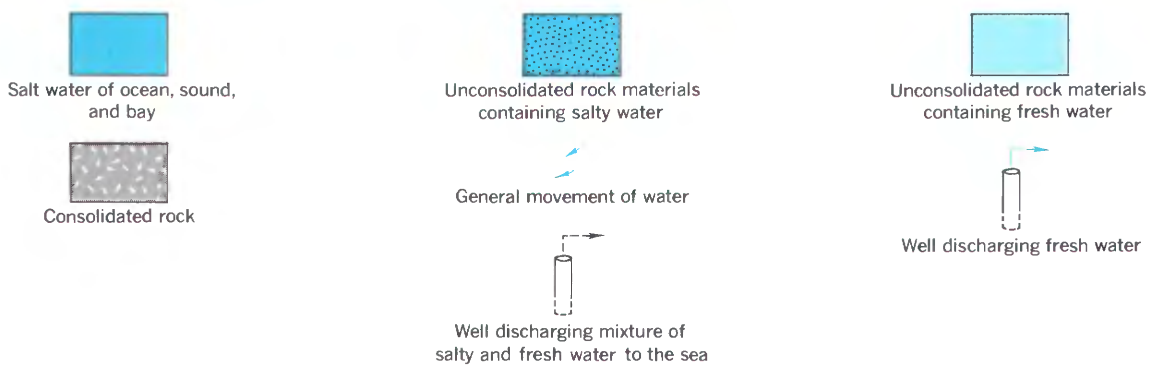
Unlike the previously described barrier-injection wells, pumping-trough wells will not increase the amount of potable water recharging the ground-water system; therefore, although a pumping trough may increase the safe yield by alleviating or preventing an undesired result (salt-water encroachment), it will not significantly increase the total amount of fresh ground water that could ultimately be developed. Pumping troughs could, however, postpone the time when production wells near the shorelines become contaminated with salty water.

If and when there is an increase in the amount of overdevelopment from the fresh ground-water reservoir upgradient from a pumping trough, the amount of water withdrawn from the pumping-trough wells also would have to be increased to maintain the stability of the salt-water front. Therefore, in accordance with the water-budget concept, continued overdevelopment of the fresh ground-water reservoir and continued withdrawals from the pumping-trough wells could ultimately deplete the fresh ground-water reservoir. Under these circumstances, adoption of pumping troughs as the chief or sole water-management tool on Long Island would involve accepting the concept of planned overdevelopment. However, in conjunction with other water-conservation measures, such as increased artificial recharge or salvaging natural discharge, pumping troughs might be used effectively as a part of any one of several alternative plans designed to develop a given quantity of potable ground water perpetually.

PLATE 9E
ALTERNATIVE METHOD OF MANAGING THE WATER RESOURCES OF LONG ISLAND, NEW YORK–PROPOSAL TO DEVELOP PUMPING TROUGHS



EXPLANATION



Proposal to inject treated waste water through recharge basins

At present, several agencies concerned with the development and management of the water resources of Long Island are studying the feasibility of artificially recharging the shallow ground water with large amounts of sewage-plant effluent through shallow recharge basins (pl. 9F). In Nassau County, for example, plans have been developed to discontinue the use of virtually all the remaining domestic cesspools and septic tanks (mainly in the eastern half of the county) in the next several decades. The area will be sewered, and the waste water will be treated in a large-scale sewage-treatment plant that will be constructed in the next several years. County officials presently are considering the possibility of upgrading the quality of some of the plant effluent by means of tertiary treatment, and as a first step, of pumping as much as 27 mgd of the water into barrier-injection wells. A later phase of the proposed program is to ultimately inject 58 mgd of highly treated sewage-plant effluent (that meets the standards for potability) into a network of shallow recharge basins roughly parallel to the line of proposed barrier-injection wells, but approximately in the middle of the island.

Also, in Suffolk County, a regulation recently established by the Suffolk County Health Department requires that all new housing developments in the county having 100 or more individual homes may not use individual cesspools, but must be equipped instead with communal sewage-treatment and disposal facilities. As a result, several housing developments in Suffolk County presently are discharging treated sewage-plant effluent into recharge basins, and the total quantity of such artificial recharge probably will increase markedly in the future. To guide this and similar methods of water-resources management, a cooperative research study currently is being made by the Health Departments of New York State and Suffolk County. The study is directed toward developing and evaluating procedures for treating domestic and industrial waste water and injecting the treated water into shallow wells (New York State Temporary Commission on Water Resources Planning, 1966, p. 139–160 and 236–239).

The major reason for discontinuing the disposal of untreated domestic wastes through individually owned cesspools and septic tanks is to minimize the pollution of the ground-water reservoir. However, if the water that formerly recharged the ground-water reservoir by way of the cesspools and septic tanks is instead discharged to the sea after being treated, the resulting loss of water will substantially increase the overdraft on the ground-water system. The alternative proposal of returning the waste water to the ground-water reservoir by means of recharge basins or injection wells has the advantage of reducing or eliminating such overdraft.

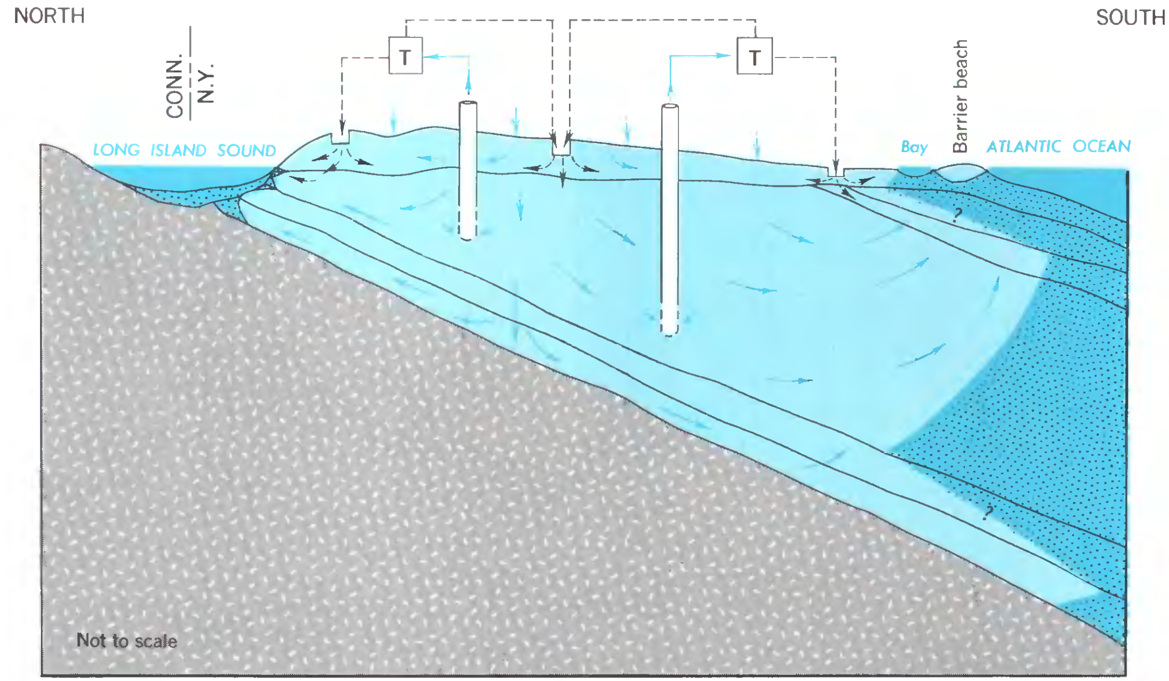
Theoretically, if all the water pumped from the ground-water reservoir is returned after use by means of recharge basins, injection wells, or other methods, the safe yield of the system would be almost limitless were it not for water-quality considerations and the differences between horizontal and vertical permeabilities. Each time that the water is recirculated (pumped from the ground, used, treated, and returned underground) the quality of the water would deteriorate unless certain demineralizing treatment methods were used. Such methods

PLATE 9F

ALTERNATIVE METHOD OF MANAGING THE WATER RESOURCES OF LONG ISLAND, NEW YORK—PROPOSAL TO INJECT TREATED WASTE WATER THROUGH RECHARGE BASINS

are possible, but are at present moderately expensive. Even if demineralization is not employed, tertiary treatment of waste water and subsequent recharging of the ground-water reservoir could increase the safe yield of the system manyfold, and might extend the usefulness of the ground-water reservoir of Long Island over hundreds of years.

If most of the future pumpage is from the deeper artesian aquifers and if the pumped water is returned to the shallow aquifers after use, a local imbalance might result in the deeper aquifers. Because vertical permeabilities ordinarily are much less than horizontal permeabilities, water returned to the shallow aquifers may not move downward into the deeper aquifers as rapidly as it is pumped from these aquifers, with the result that some water pumped from the deeper aquifers will be replaced instead by laterally encroaching salty water.



EXPLANATION

Salt water of ocean, sound, and bay

Unconsolidated rock materials containing salty water

Unconsolidated rock materials containing fresh water

Consolidated rock

Well discharging fresh water

General movement of fresh water

T
Tertiary sewage—treatment plant

Movement of treated waste water

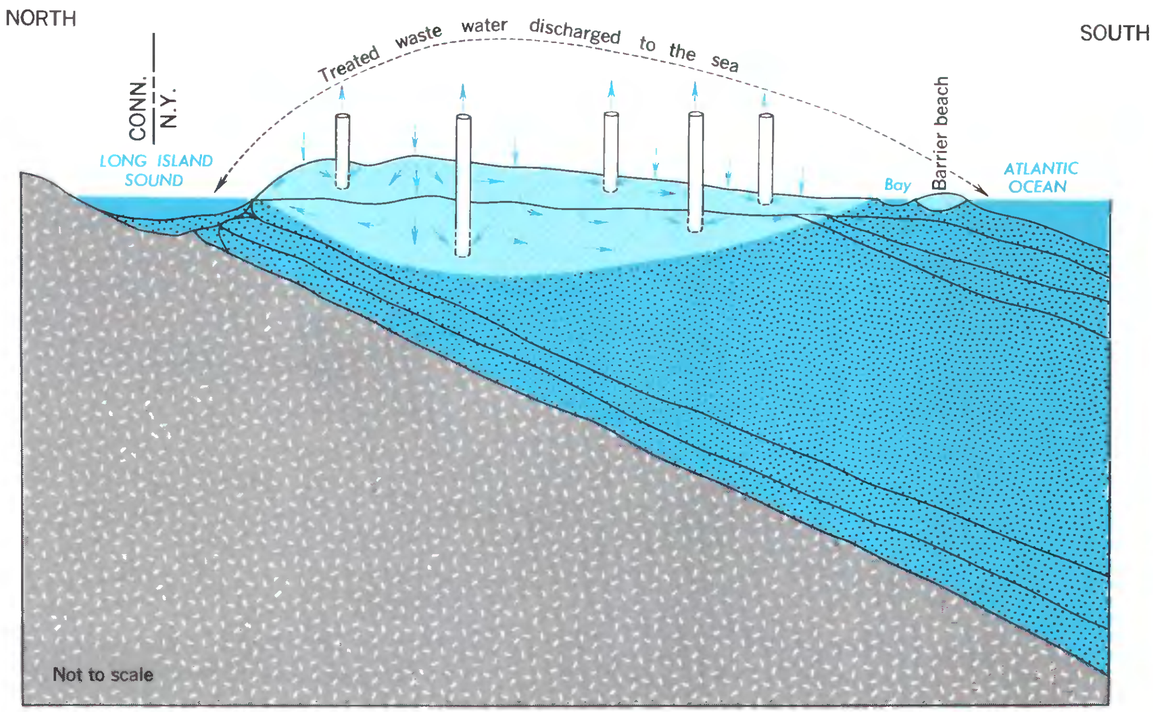
Recharge basin

Proposal to permit salt-water intrusion

Wedges of salty ground water extend inland from the points of intersection of the aquifers on Long Island and the bordering ocean, bays, and Long Island Sound. The landward extent or length of a wedge of salty water in a given aquifer is about inversely proportional to the rate at which ground water is discharging from the aquifer into the ocean (Todd, 1959, p. 281). This relation means that salty ground water will move inland if the seaward movement of fresh ground water is decreased. It follows, therefore, that if a management decision is made to maintain the interfaces between fresh and salty ground water in the positions that existed under natural or predevelopment conditions, then roughly 470 mgd (p. 58) of fresh ground water must be allowed to discharge by subsurface outflow from the water-budget area toward the sea. On the other hand, if the salt-water wedges are permitted to move inland, an additional quantity of fresh ground water could be withdrawn from the aquifers and used consumptively; the additional amount made available thereby would be roughly proportional to the increase in the lengths of the extended salt-water wedges. Stated in other terms, the yield of the ground-water reservoir of Long Island could be increased substantially if it were deemed tolerable to permit the salt-water wedges to move inland, and thereby allow some of the presently operating production wells to become contaminated with salty water (pl. 9G).

The principle of permitting the salt-water wedges to move inland to new stable positions that require less subsurface outflow of fresh ground water to the sea could be employed in conjunction with any one of several other alternative methods of development. For example, all the treated waste water might be discharged directly into the sea (as shown on plate 9G), or some or all of it might be returned to the ground-water reservoir through recharge basins or injection wells. In any event, allowing the salt-water wedges to move further inland than their present positions, under carefully controlled conditions, might be a desirable method of managing the fresh ground-water resources of Long Island.

PLATE 9G
ALTERNATIVE METHOD OF MANAGING THE WATER RESOURCES OF LONG ISLAND, NEW YORK—PROPOSAL TO PERMIT SALT-WATER INTRUSION



EXPLANATION

Salt water of ocean, sound, and bay

Unconsolidated rock materials containing salty water

Unconsolidated rock materials containing fresh water

Consolidated rock

Well discharging fresh water

General movement of fresh water

Proposal to develop shallow skimming wells

In the water-budget area of Long Island, the estimated rate at which ground water discharges into streams and thence into the bodies of salty surface water bordering the island is 320 mgd (p. 46). Much of this water, and perhaps some that leaves the water-budget area as subsurface outflow and evapotranspiration, could be salvaged for beneficial use by means of "skimming" wells. Where streams are connected hydraulically to an aquifer, as they are on most of Long Island, water can be diverted from the streams by pumping from wells that tap the same aquifer. Accordingly, it is theoretically possible to capture, by means of a network of carefully spaced shallow wells (pl. 9H), as much as 300 mgd or more of streamflow on Long Island that is currently discharging into salty water. Such wells are commonly referred to as skimming wells because they skim fresh water from very near the top of the ground-water reservoir. As shown on the accompanying plate, skimming wells could be used in conjunction with a network of shallow and deep wells further inland.

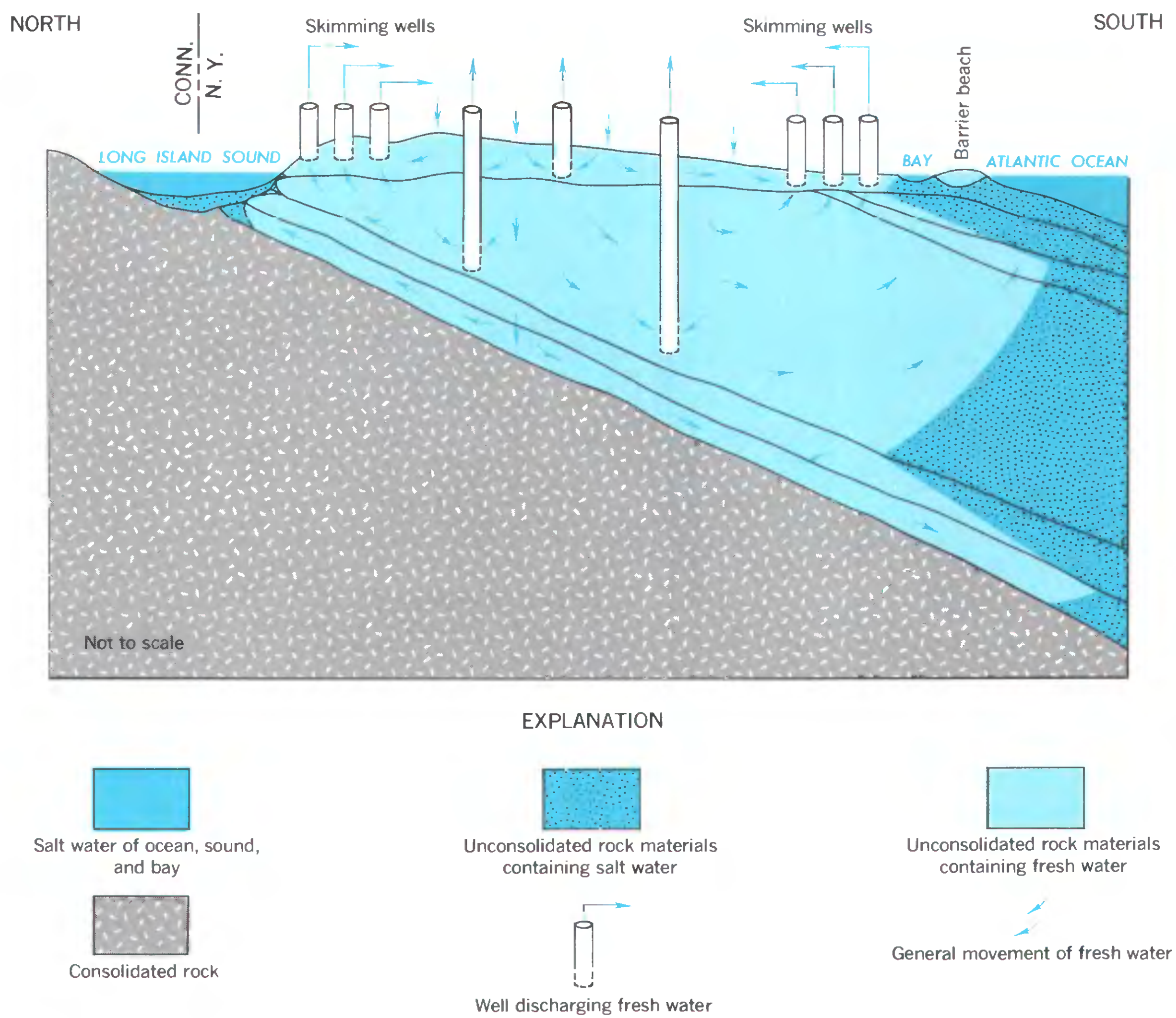
Inasmuch as skimming wells theoretically could salvage roughly 300 mgd of the natural ground-water discharge from the upper glacial aquifer, the safe yield of the system could be increased by this amount. The overall safe yield, of course, might be considerably more, depending upon what other management methods were employed. Salvaging natural ground-water discharge by the use of skimming wells would be largely at the expense of streamflow. Moreover, the resulting decrease in streamflow to the sea would change the salinity of the bays and estuaries, and thus might alter the plant and animal life therein. The resulting possible harmful effects and the loss of some of the esthetic features associated with the streams would have to be considered when evaluating the possible application of skimming wells.

Because the chemical quality of much of the shallow ground water has been affected adversely by cesspools and septic tanks, the quality of the water withdrawn from the skimming wells might be less than optimum, and, therefore, the water might require some treatment prior to use. Nevertheless, skimming wells seemingly could increase the safe yield of the Long Island ground-water reservoir substantially with only moderate cost and effort.

In summary, the foregoing alternative methods of developing and managing the water resources of Long Island, applied individually or in combination with each other, represent only a few of the many possibilities. Numerous other alternatives as well, ranging from nuclear desalination of sea water to the conversion of Long Island Sound into a fresh-water reservoir (A. J. Pansini, written communication, 1964; and Gerard, 1966, p. 870–871) should be carefully evaluated. It is beyond the scope of this report to speculate upon (and much less to evaluate) all the alternatives that will become economically and technologically possible in the future. The major point that should be kept in mind is that the safe yield of the ground-water system of Long Island is not a fixed value, but depends upon the nature of the water-management decisions, and how the system responds to the enactment of these decisions in accordance with certain immutable physical and chemical laws.

PLATE 9H

ALTERNATIVE METHOD OF MANAGING
THE WATER RESOURCES OF LONG ISLAND, NEW YORK—
PROPOSAL TO DEVELOP SHALLOW SKIMMING WELLS



10 SUMMARY

The preceding chapters of this atlas are summarized as follows:

CHAPTER 1 — LONG ISLAND, THE LAND AND ITS PEOPLE

A. Long Island, which extends about 120 miles into the Atlantic Ocean, has a total area of about 1,400 square miles. It includes four counties—Kings, Queens, Nassau, and Suffolk. The former two counties are boroughs of New York City.

B. The major landforms of Long Island are (a) the hilly terminal moraines that cover the northern and eastern parts of the island, (b) the gentle outwash plain that extends southward from the terminal moraines to the south-shore bays, (c) the deeply eroded headlands along the north shore, and (d) the offshore barrier beaches. These features were formed mainly near the close of and following the last ice age.

C. The population of Long Island in 1965 was 6.8 million; 4.5 million people lived in Kings and Queens Counties, and 2.3 million lived in Nassau and Suffolk Counties. In general, the population density of the island decreases from west to east.

D. Kings County is the most highly urbanized part of Long Island, and the intensity of urbanization decreases generally eastward.

CHAPTER 2—HOW AND WHERE THE WATER IS FOUND

A. Long Island's water is classified into three categories—atmospheric water, surface water, and subsurface water. Although the salty water also is important to the area, the fresh-water resources are emphasized in this report.

B. Streams and lakes comprise most of the fresh surface-water bodies on Long Island. Practically all the streams in their lower reaches become estuarine and are subject to tidal influences. Two major types of lakes are found on the island, water-table lakes and perched lakes. Many of the natural lakes, such as Lake Ronkonkoma, fill depressions formed where blocks of ice were buried during the last ice age and subsequently melted.

C. The ground-water reservoir of Long Island comprises a saturated wedge-shaped mass of unconsolidated deposits that overlie nearly impermeable consolidated bedrock. These deposits, which consist of gravel, sand, silt and clay, and mixtures thereof, attain a maximum thickness of about 2,000 feet.

D. Subsurface water includes ground water in the zone of saturation and vadose water in the zone of aeration. A major difference between the two types of water is that ground water will flow into a well under the force of gravity, and vadose water will not. Two major types of aquifers are found on Long Island—confined aquifers that contain ground water under artesian conditions, and unconfined aquifers that contain water under water-table conditions.

E. The water table of Long Island in 1965 was a somewhat subdued replica of the land-surface topography. The altitude of the water table is highest beneath the terminal moraines and decreases progressively toward the coasts. The artesian-pressure surfaces near the middle of the island generally are a few feet lower than the water table, and near the coasts they are a few feet higher than the water table.

F. In this report, quantitative estimates are made mainly for the "water-budget area" and for the index period water years 1940–65. The "water-budget area" includes about 760 square miles of Nassau and Suffolk Counties; it excludes Kings and Queens Counties, the eastern forks, and narrow bands of land near the coasts where the streams are estuarine. The 26-year period, water years 1940–65, was chosen mainly because of the availability of comparable hydrologic data.

G. It is estimated that the volume of material saturated with fresh ground water in the water-budget area is about 180 cubic miles, and that about 3–6 trillion gallons of fresh water would drain from these deposits if they could be unwatered.

H. Fresh ground water, salty ground water, and salty surface water are hydraulically interconnected on Long Island. A zone of mixed ground water (the "zone of diffusion") generally separates the fresh and salty ground water.

CHAPTER 3—WHERE THE WATER COMES FROM

A. Under natural conditions, precipitation was the ultimate source of virtually all the fresh water on Long Island. The average annual precipitation on the island is about 44 inches, which averages about 1,600 mgd for the water-budget area.

B. A major feature of the precipitation pattern on Long Island is the small range in average monthly values, from a minimum of about 2.5 inches to a maximum of about 5 inches. Average monthly precipitation is about 3.7 inches.

C. Annual precipitation at Setauket averaged 44.6 inches, and ranged from a high of 56.4 inches to a low of 31.9 inches. The odds against the annual precipitation being as low as 31.9 inches, as it was during the drought in water year 1965, are nearly 100 to 1.

CHAPTER 4—WHERE THE WATER GOES

A. Evapotranspiration of precipitation soon after it falls, which averages about 21 inches per year, represents the largest element of fresh-water discharge from the hydrologic system of the water-budget area. Evaporation from open bodies of water is negligible in terms of the overall water budget.

B. Average annual streamflow to the sea is about 340 mgd of fresh water from the water-budget area. Most of this stream water (about 95 percent) is derived from ground-water seepage into the streams.

C. About 5 percent of the streamflow (roughly 20 mgd) that discharges into the sea is direct runoff.

D. Streamflow to the sea normally is greatest in April and least in September. For the most part, however, streamflow on Long Island is characterized by small variations in monthly flow.

E. Practically all the precipitation that is not consumed by evapotranspiration or does not discharge into the sea by direct runoff recharges the ground-water reservoir. The estimated average annual recharge is about 23 inches, which is equivalent to about 820 mgd for the water-budget area.

F. Natural ground-water movement on Long Island is mostly northward and southward from the ground-water divide toward the sea. The estimated average natural ground-water discharge in water years 1940–65 was 820 mgd and occurred as follows: 320 mgd discharged into streams; 470 mgd discharged from the water-budget area as subsurface outflow; 15 mgd of springflow discharged almost directly into the sea along the north shore; and 15 mgd discharged directly from the ground-water body by evapotranspiration.

CHAPTER 5—CHEMICAL AND PHYSICAL PROPERTIES OF THE WATER

A. The dissolved-solids content of Long Island's water generally increases as the water moves through the system. Precipitation commonly has the lowest dissolved-solids content, and the salty ground and surface waters have the highest dissolved-solids content.

B. One of the most significant features of the fresh water on Long Island is its very low dissolved-solids content—less than 50 ppm under natural conditions. Except for the iron content (which commonly is higher than the recommended limits) the native water is of excellent chemical quality for most uses.

C. Air temperatures and surface-water temperatures correlate closely. Shallow ground-water temperatures do not correlate as well with air temperatures, and changes in them lag several months behind changes in air temperatures.

D. Ground-water temperatures generally increase with depth owing to the geothermal gradient. The average increase in the temperature of ground water throughout most of Long Island is about 1°F per hundred feet of depth.

CHAPTER 6—SUMMARY OF RELATIONS BETWEEN THE COMPONENTS OF THE HYDROLOGIC SYSTEM

A. Prior to its exploitation by man, the hydrologic system of Long Island was in a state of long-term dynamic equilibrium—average annual inflow and outflow were equal.

B. Average total inflow to the water-budget area (precipitation) was 1,600 mgd; ground-water recharge was 820 mgd, direct runoff was 20 mgd; and ground-water discharge to streams was 320 mgd. Outflow from the water-budget area included evapotranspiration of precipitation (760 mgd), subsurface ground-water outflow (470 mgd), streamflow discharging to salt water (340 mgd), evapotranspiration of ground water (15 mgd), and springflow (15 mgd).

C. Average monthly ground-water levels correlate closely with the cumulative departure from estimated average monthly recharge.

D. Estimated annual recharge does not correlate very well with annual average ground-water levels, which, however, correlate closely with the annual flow of the 19 major streams on Long Island.

CHAPTER 7—HOW MAN HAS CHANGED THE NATURAL HYDROLOGIC SYSTEM

A. Ground-water development on Long Island has progressed through three major stages: (1) The first stage was characterized by individually owned shallow wells used for water supply, and cesspools used for the disposal of domestic wastes. (2) The second stage was characterized by deep public-supply wells tapping the artesian aquifers, and individually owned cesspools. (3) The third stage was characterized by deep public-supply wells and large-scale

communal sewage-collection and disposal systems. The second and third stages have resulted in local overdevelopment of the ground-water system and concurrent salt-water encroachment into the fresh-water aquifers.

B. The three major stages of development, as well as transitional stages, can be observed presently in different parts of Long Island. In general, the degree of development decreases from west to east.

C. Streamflow in the highly urbanized parts of Kings and Queens Counties has been virtually eliminated. Streamflow has not been markedly affected in most of the water-budget area, but locally direct runoff has increased owing to the construction of impervious surfaces.

D. Ground-water pumpage on Long Island increased from about 220 mgd in 1940 to about 430 mgd in 1965. Gross pumpage in 1965 was about 24 mgd in Kings County, 78 mgd in Queens County, 210 mgd in Nassau County, and about 120 mgd in Suffolk County.

E. About 500–600 mgd of treated and untreated sewage water was discharged into the sea from Kings and Queens Counties in 1965. All but about 100 mgd of this water was derived from the upstate New York City municipal-supply system. Virtually all the sewage-plant effluent that was discharged into the sea from Nassau and Suffolk Counties was derived from the ground-water reservoir.

F. More than 2,000 recharge basins in Nassau and Suffolk Counties recharge the ground-water reservoir with substantial quantities of direct runoff from storms.

G. In 1965, about 46 mgd of ground water, following its use mainly for air conditioning and other industrial purposes, was injected into more than 1,000 "diffusion" wells (recharge wells) on Long Island.

H. Injection of warm water into diffusion wells and changes incidental to suburban development, locally have caused increases in the temperature of the ground water.

CHAPTER 8—MAJOR WATER PROBLEMS RESULTING FROM THE ACTIVITIES OF MAN

A. Ground-water levels decline near pumping wells as a function of the rate of pumpage, and the chloride content of water from wells in and near the zone of diffusion increases as pumpage increases.

B. Marked overdevelopment of ground water in most of Kings County and in parts of Queens County has resulted in widespread lowering of water levels and the contamination of substantial parts of the fresh ground-water reservoir in these counties. Since the late 1930's, net ground-water withdrawals have decreased in Kings County, and ground-water levels have recovered substantially.

C. Three major tongues or wedges of salty ground water are found in southwestern Nassau and southeastern Queens Counties. The deeper wedge has moved inland in response to local ground-water overdevelopment an average distance of about 1,000 feet since the early 1900's. The intermediate wedge has not moved as far inland since that time.

D. Much of the shallow ground water is contaminated with domestic wastes that were discharged into the ground through cesspools and septic tanks. Water from many shallow wells contains ABS, a

chemical compound used in household detergents, in concentrations sufficient to cause the water to foam.

E. Some of the shallow ground water also is contaminated with industrial wastes. For example, in the South Farmingdale area, some of the shallow ground water contains cadmium and chromium ions in amounts exceeding those considered objectionable in public-supply water.

CHAPTER 9—ALTERNATIVE METHODS OF DEVELOPING AND MANAGING THE WATER RESOURCES OF LONG ISLAND

A. The hydrologic system of Long Island must respond to any water-management program in a way that is consistent with the water-budget equation. The amount of fresh ground water in storage ultimately will be depleted if total outflow perpetually exceeds total inflow.

B. The safe yield of the ground-water reservoir of Long Island—the amount of water which can be withdrawn from it annually without producing an undesired result—can range between wide limits depending upon (a) future management decisions, (b) the amount of natural discharge that is salvaged, and (c) the amount of additional ground-water recharge that is induced.

C. Continuation with the present methods of developing and managing the water resources of Long Island would, in effect, involve accepting the concept of planned overdevelopment. Eventually, the fresh ground-water reservoir might be depleted.

D. A network of barrier injection wells, by means of which the ground-water reservoir is recharged with highly treated sewage-plant effluent, might be used to prevent or reduce the contamination of the fresh ground water with salty ground water, and thereby increase the safe yield of the system. According to a proposal presently being considered, the sewage-plant effluent would be treated so that it meets the commonly accepted standards for potability.

E. Pumping troughs, consisting of a network of wells near the shore from which a mixture of fresh and salty water would be withdrawn, also might be used to prevent or minimize salt-water intrusion. This technique alone would not significantly increase the total amount of fresh ground water that ultimately could be developed.

F. Another possible method of conserving the water resources of Long Island is artificial recharge through recharge basins, using highly treated sewage-plant effluent. This method could increase the safe yield of the system manyfold; however, it would cause the dissolved-solids content of the water to gradually increase.

G. The landward length of a salt-water wedge is about inversely proportional to the amount of fresh subsurface outflow to the sea. Therefore, the safe yield of the ground-water system of Long Island could be increased substantially if the salt-water wedges are permitted to move inland toward new equilibrium positions.

H. Most if not all the ground water discharging into streams and thence into the sea could be salvaged by skimming wells. Accordingly, this method of development could increase the safe yield of the ground-water system by as much as 320 mgd, provided that the accompanying side effects could be tolerated. Numerous other alternative methods of developing and managing the water resources of Long Island are possible. These should be evaluated within the context of the water-budget concept.

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This program provides for 50–50 cost sharing of water-resources investigations. In 1967, the total expenditures for this program amounted to about $1 million.

The water-resources investigations provided by this program offer an appraisal of the quantity and quality of both surface and ground waters in each region studied. Areal surveys, streamflow gaging, water-quality studies and selective mapping of ground-water geology to determine the size, location and hydraulic properties of New York's natural underground reservoirs are a part of the hydrologic appraisal of every region.

The New York State Water Resources Commission is the central policy-making body for water in New York State. The U.S. Geological Survey is the principal agency charged by Congress with appraising the water resources of the United States. Thus, the survey has gained broad experience in many phases of water resources surveying, testing, and evaluation. Partnership between the Water Resources Commission and the U.S. Geological Survey ensures the completion of studies that will provide basic data and interpretive reports in support of New York State's Regional Water Resources Planning and Development Board programs which are undertaken under Part V, Article V of the New York State Conservation Law.

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